Forestry

TIMBER CRUISING

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TIMBER CRUISING

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INTRODUCTION

The most important part of learning to cruise timber is developing the powers of observation. A cruiser who observes intelligently soon learns to appreciate the importance of considering and weighing all the factors that influence timber volume and value. The ambition and determination of any man who desires to become an efficient timber cruiser should be to train himself to recognize and take stock of all the factors and conditions that affect the accuracy of his estimates. If this procedure is carried out good judgment, a primary requirement in cruising, will naturally result, because judgment is the product of observation, training, and experience.

The purpose of part I of this manual is to explain in simple terms the principles and methods of timber cruising. Part II deals with the elements of statistical analysis and the theory of sampling. It shows, also in simple terms, how methods of statistical analysis can be put to use in estimating timber volume.

It is obviously impossible for any cruiser or group of cruisers, no matter how much experience they have had, to present all the details of cruising so completely that an inexperienced man can become a competent timber cruiser by simply reading the discussions. The principles of estimating gross volumes can be learned in a few weeks by any man having a rudimentary education if he has natural talent and an interest in this line of work; but much experience and close observation are required before cull or quality of timber can be readily estimated. Timber cruising deals with many factors affecting timber volume, such as percentage of defect, breakage, limits of merchantability, and quality of timber, that vary widely from region to region and among different species.

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PART I

CHAPTER 1. NATURE AND INTENSITY OF CRUISE

The primary purpose of any timber cruise is to determine the net volume and species of timber on the tract under consideration as accurately as the time and funds allotted for the work permit. The use for which the information is intended and its value to the user determine the nature and intensity of the cruise. All the objects of the cruise should be known before detailed plans and instructions for collecting the desired information are formulated. An understanding as to the factors of utilization and of the units in which estimates are to be made, for example board feet, cords, or poles, is essential. Often it is necessary that the cruiser have a knowledge of log grades, and of grades of lumber, pulpwood, poles, etc. Often reliable information is needed on transportation facilities, and on management factors such as forest types, site quality, age classes, density, growth rates, disease, insects, fire, wind throw, game values, and recreational use.

As a general rule, not all the trees on the entire tract are counted and recorded. The timber volume estimate is made by applying to the whole tract the results of an examination of part of it. Determination of timbered area, therefore, is usually very important. In an intensive cruise of a small to medium-sized tract, the timbered area is usually determined from a map that is prepared in the field as the cruising progresses. The areas of the various cover types should be determined if a cruise of comparatively high accuracy is required, particularly if the total area is small. If the types are accurately shown on a map, the area of each can be determined with a planimeter. For a unit of several thousand acres for which no very accurate and detailed map is made, the areas of different types and forest conditions should be determined by use of an adequate number of sample plots, uniformly distributed over the area and carefully classified on the ground. If a field tally made in this manner showed, for example, that 25 percent of all the sample plots were of a certain type and forest condition it would be reasonable to assume that 25 percent of the entire tract was of this particular type and condition.

Variation with Specific Purpose of Cruise

Cruising for Purchase

If a cruise is made for purchase, a high degree of accuracy is ordinarily considered essential. In such a case, the quality of the timber is as important as the quantity. Often the cruise must include determination not only of volume and quality but also of value. In the early days when timber was plentiful in the United States, the timber on many thousands of acres was sold at fixed per-acre prices, with no attempt to cruise it. Careful determination of value was almost never required, because stumpage prices were low and the purchaser usually figured on a sizable overrun. Today the situation is quite different.

Often it is necessary to determine the quantity of timber that can profitably be logged. On a tract supporting 350 million board feet of physically merchantable timber, careful analysis may show that only 250 million board feet can be operated profitably. The cruiser may be required not only to determine the volume of loggable timber but also to furnish some basis for calculating the approximate realization value, or the spread between the cost of operation and the selling value of the finished product. This involves a detailed timber appraisal. The appraisal may constitute a separate operation by specially trained men, but often both cruise and appraisal are performed by the same men.

When a cruise is made for purchase the following information is usually required:

(1) Gross volume of timber in merchantable trees.

(2) Net volume of timber in merchantable trees (gross volume less cull and breakage).

(3) Marginal tree size and marginal log size.

(4) Recoverable (or loggable) volume, i.e., the quantity of timber that can be removed at a profit.

(5) Logging conditions.

(6) Most practical method of operation.

(7) Estimated costs of operation.

(8) Quality of timber.

(9) Percentages of lumber grades that can be produced, calculated separately for each species.

Cruising for purchase may also involve obtaining information for a rough management plan.

Cruising for a Logging Plan

In a cruise made for a logging plan, if the plan is to be based primarily on liquidation the chief purpose is to record the topography and the location of the recoverable timber. Usually a separate cruise must be made of each small logging unit. A detailed topographic map will enable the logging engineer to determine the natural logging units, and will serve for definite planning for the operation. A very detailed cruise of the merchantable timber, by species, is ordinarily required, and an estimate of the net volume of loggable timber. A density map showing the stand of timber per acre by logging unit is considered necessary by some lumbermen.

If a cruise for a logging plan is made on property that is to be put under sustained-yield management, a complete inventory of the growing stock is required and information on rate of growth is needed. A complete tally of the timber by species and diameter class may be required. The timber to be cut and the timber to be left are estimated separately.

Cruising for Management

A cruise for management purposes ordinarily involves obtaining most of the items of information required in a cruise for purchase, and calls for additional information.

The primary purpose of a management plan for a forest tract is to safeguard future yields of timber from the tract, partly by relating the annual cut during any period to the estimated growth of merchantable timber during that period. A cruise for management purposes is in order only if cutting operations are likely to begin within the next few years.

The intensity of cruise varies with the size of the tract, but in any case it is necessary to determine the age classes, species, merchantable volume, and annual growth rate of the timber on the entire tract. These determinations need not be made in great detail for small subdivisions, such as logging units, if reliable information for the entire tract is available to establish the necessary control for the cutting operation. The cruise must yield the following information:

(1) Total forest land within management unit.

(2) Total net volume of timber by species, age class, and 2-inch diameter class. (Number of trees per acre by 2-inch diameter class also should be shown.)

(3) Total net volume of loggable timber, classified by quality.

(4) Areas of different types.

(5) Areas of different age classes.

(6) Areas of different site qualities, such as good, medium, or poor.

(7) Net growth, either current annual or periodic realizable annual.

(8) Best type of land use.

(9) Possible conflicting uses.

(10) Economic importance to local communities.

The information necessary for a preliminary management plan for a large tract can be obtained at comparatively small expense. For a tract of 100,000 acres or more such a management plan does not require a cruise of more than 1 percent, if the sample plots are uniformly distributed over the area. Reliable information on annual growth can be obtained by boring representative trees on the sample plots. Intensive application of the plan may require a complete tally of all trees, or a 100-percent estimate, showing the species and diameter class of the trees to be cut and also of the trees to be left.

In European countries where forestry has been practiced for many decades, management plans are based largely on accumulated experience. This is the most satisfactory way to prepare a workable management plan. Large expenditures in the preparation of a detailed management plan are ordinarily not justified.

Detailed information on individual compartments can best be obtained just before cutting takes place.

Cruising for a Policy Statement

As a basis for formulating a policy regarding timber that is inaccessible and not in demand, and the current annual growth of which exceeds any annual cut expected in the near future, a very rough cruise and map will serve. Under these conditions an intensive cruise is not justified; detailed information will not be needed so long as the timber is not in demand. For this reason an examination made primarily for a policy statement is nothing more than a rough reconnaissance.

Cruising or Checking for Security of a Loan

A cruise or check to determine whether a timber property is acceptable as security for a loan usually consists of both timber-valuation work and check cruising. Usually the tract is first examined by a timber expert, who should be thoroughly familiar with logging methods and costs and with timber quality and value. It is the duty of the expert to determine the feasibility of operation, the approximate cost of operation, and the volume and quality of the timber. This work is followed by a detailed check of well-distributed sample plots sufficiently extensive to show whether the original estimate is reliable.

Cruising for Special Purposes

In cruises made for certain special purposes a complete, or 100-percent, estimate is required. This is true of most cruises made for the purpose of determining the quantity of timber suitable for such uses as peeler logs, high-grade veneer logs, and certain grades of export stock. Trees suitable for these purposes usually are widely scattered. This type of work can be done only by an expert.

Cruising for National Inventory

A special type of cruising is required by the Nation-wide Forest Survey now in progress in the United States. Much of the work requires mensurational experts, and all those taking part must receive intensive training.

The survey embraces determination of the following for each of the major forest regions:

1. Area of forest land, its condition, area of cover types and timber age classes, total quantity of timber in board feet, cords, and cubic feet.
2. Rate of timber depletion from cutting operations, fires, insects, disease, wind throw, etc.
3. Annual timber growth, the allowable annual cut, and the relation of the latter to current annual depletion.
4. Total timber requirements for all purposes.

It is evident that a very intensive survey cannot be made; the cos would be too great, and too much time would be required. Reliable information cannot be obtained for small units except in cases in which timber cruises are already available. If cruises are available they are collected and compiled by section, township, watershed, economic unit, etc., then checked by experts. The samples for check cruising are so selected as to give good representation of the entire tract. The number of samples selected and the percentage of area checked depend on the size of the tract. The check cruising may be done by either the strip or the line sample-plot method. The check cruises are compiled currently. When the differences between original cruise and check cruise run uniformly high or low, reliable adjustment factors can be computed and used to correct the original estimates.

Areas for which cruises are not already available are cruised by the line sample-plot method. Lines are run 1 to 10 miles apart, and sample plots are taken at regular intervals along them. The work on the sample plots is done with a high degree of accuracy. A separate record is kept of the volume on each individual sample plot; this makes it possible to subject the data to statistical analysis. The errors of estimate can be computed closely enough for all practical purposes. Units of several million acres are usually as small as can be used for compiling the information; the results are not reliable for smaller units. This sampling method, which gives less than one-tenth of 1 percent coverage, yields more reliable estimates of total volume of timber on a tract of 10 million acres than a 20-percent cruise would yield for a tract of 2,000 or 3,000 acres of similar timber. In other words, the percentage error of estimate is less for the large tract.

Aerial photographs are very valuable in connection with national-resource surveys (and in fact with any type of cruising), because they show accurately the extent of timbered areas.

Cruising for Turpentine Operations

Cruising for turpentine operations can correctly be considered timber cruising, although it may not deal with volume. The naval stores belt of the Deep South comprises an area of approximately 30 million acres, and naval stores production is a very important factor in the economic life of that region.

Two general types of cruise are made for naval stores operations, one on areas that are to be leased for immediate operation and the other on areas that are to be purchased. If a cruise is made for a lease, the information required is a record of the number per acre of longleaf and slash pine trees 9 inches or more in diameter at breast height, by diameter class. It is advantageous also to learn something about the distribution of these trees. The minimum number of trees per acre that could profitably be worked should be determined, and any areas having less than this number should be eliminated from the cruise. It is well, also, to show the location of such areas on a map. A cruise for purchase, in addition to showing number per acre of trees of the turpentine species 9 inches or more in diameter, should give definite information as to areas of old growth, second growth, marsh, swamp, saplings, reproduction, burns, clean-cut land, etc. A complete record of the number per acre of trees of turpentine species of all diameter classes from 1 inch up may be required. The prospective purchaser wants to know the rate of diameter growth and the numbers of trees below the 9-inch diameter class that will grow to workable size within 10 years, within 20 years, etc. Information on the rate of mortality to be expected is very valuable. The purchaser wants to know also the quantity of merchantable timber of other species.

Cruises for turpentine operations can be made by either the strip or the line sample-plot method.

Cruising Stumps for Distillation Operations

In certain sections of the South, large quantities of longleaf pine stumps are used in distillation plants for extraction of turpentine and other products. The stumps are counted on strips or sample plots. For final estimate, the number of stumps is expressed in tons per acre. It takes from 5 to 7 stumps to make a ton, depending in part on whether the stumps are pulled or blasted. The area must be open enough to permit stump-pulling machines and trucks to pass over it. Dense stands of poles make an area unmerchantable for stump operations.

Variation with Logging and Utilization Practices

The nature and intensity of a cruise depend in part on the local logging and utilization practices. In many cases, the cruiser must know the practice of the individual or company for whom the cruise is to be made. Some companies utilize very closely, others plan not to utilize any trees or logs that will not pay the cost of operation plus some margin for profit. Stumpage cost often materially affects the intensity of utilization. Because of variations in this cost, there is sometimes a wide difference in utilization practices between individual operators in the same region cutting the same species. Some cruising firms make it their practice to cruise all material that is physically merchantable and then show in their report what portion of the cruised volume is recoverable under each of several different utilization standards. The timber cruiser of the future will have to know much about such matters as timber quality, log grades, yield of lumber grades, logging methods and costs, practical forest management, most profitable cutting practices, growth of timber, and building up growing stock by light selection cutting based on short cutting cycles. In other words, it will be necessary for him to have a fair knowledge of forest mensuration, forest management, and logging engineering.

Logging Methods

In some regions the method of logging employed often materially affects the net volume that can be removed. This is clearly illustrated in the Douglas fir region, on the Pacific Coast. If an operator makes a clean cut in a heavy stand of Douglas fir the breakage alone may be as much as 25 percent. Loss in the cedar due to breakage and splitting may total as much as 40 percent. High-power skidders add to the losses in volume, particularly in cedar. If the timber is cut in two or more operations instead of one and logged with tractors, the breakage is much less. If the timber on a similar area is cut selectively and logged with tractors, the loss by breakage may be no more than 10 or even 5 percent.

Utilization Practices

Species Utilized. There is necessarily a wide variation in different parts of the United States in utilization practices for the same species. In some regions timber of certain species is not utilized, regardless of its quality. On a large proportion of the operations in the white pine type of north Idaho the hemlock, white fir, western larch, and Douglas fir are not utilized except in very limited quantities. The reason is that these species cannot compete with the Douglas fir of the Pacific Coast, the redwood of California, or the pines of the South. Some operators in north Idaho do not require a cruise of the species mentioned; they are interested only in white pine and cedar poles. In western Oregon and western Washington the scattered hardwoods, such as alder, maple, and cottonwood, are not ordinarily estimated, even though they are more valuable for certain purposes than Douglas fir. In many regions low-quality trees of the less valuable species are not included in a cruise.

Minimum Size of Trees Cut. Variation from region to region is probably wider in minimum size of tree cut than in any other phase of utilization practice. Southern pine, on many operations, is utilized down to about 10 inches for sawlogs; but in California even valuable species such as sugar pine cannot profitably be utilized below 20- to 26-inch diameters except on unusually favorable "shows." Operators in Pennsylvania and in the Lake States commonly utilize hemlock down to 12 or 14 inches for sawlogs and to smaller diameters for pulpwood; in contrast, on the Pacific Coast hemlock trees are often utilized only to a diameter of 20 to 24 inches. The minimum tree diameter for pulpwood is about 6 inches in the South, New England, and the Lake States, but is about 16 inches on the Pacific Coast.

Minimum Size of Logs Cut. There is a wide difference also in the minimum size of logs utilized in different regions. Small trees of southern pine and small white pine trees in the New England States are often utilized to a top diameter of 6 inches, but this is about the minimum for utilization of any species in any section of the country. For large Douglas fir on the Pacific Coast, the top diameter of utilization is sometimes 25 inches. Minimum log diameter is closely related to or correlated with tree diameter at breast height. Most of the coniferous species throughout the United States when cut for sawlogs are utilized to top diameters of from 40 to 60 percent of the breast-height diameter; the general average is about 50 percent of that diameter. The diameter limit of utilization is invariably a greater percentage of breast-height diameter for small trees than for large trees, whether in the Coastal Plain region of the South, the ponderosa pine region of the Pacific Northwest, or the sugar pine region of California. Top-diameter standards vary somewhat among operators. Breakage averages should be remembered in estimating the limits of merchantability. When Douglas fir on the Pacific Coast is felled, for example, it usually breaks from the top down to a diameter of about 40 percent of the breast-height diameter.

Log Length. In most regions the cruiser's standard log length is 16 feet. The length of trees of coniferous species usually is rounded off to the nearest 16-foot log; hardwoods are often measured to the nearest half log. On the Pacific Coast the log length used in Douglas fir is often 32 to 40 feet and hardwoods, if estimated at all, may be tallied in 8-foot lengths.

Merchantable Trees and Merchantable Logs. The proportionate quantity of defect a tree may have and still be merchantable varies with species, quality, and tree size. Obviously, more defect is permissible in a high-quality tree than in a low-quality tree and more is permissible in a large tree than in a small tree.

Culling practice varies widely among different regions and different species. Much more defect is permitted in logs of good quality and valuable species than in others. A large, clear butt log might be taken if it were 60 to 75 percent rotten, but a top log might be left in the woods if it were only 25 percent rotten. The Forest Service usually requires that logs of valuable species be utilized if they are one-third or more sound, the proportion varying to some extent with quality of log; it usually requires that logs of low-value species be utilized if they are one-half or more sound.

Limits of Accessibility. The limits of accessibility are constantly changing. Within the past 10 or 15 years they have greatly receded because of improvements in logging methods, particularly the development of tractors for skidding and trucks for log transportation. Many areas that could not profitably be logged a few years ago because of the light stand per acre are good "shows" now. In some regions it is now profitable to operate in stands as light as 1,000 board feet per acre.

CHAPTER 2. UNITS OF MEASURE AND SCALING PRACTICE

Board Foot

Log Rules

If the unit of measure is the board foot, log scale, the cruiser must know what scale rule is to be used. There are wide differences among the results obtained by the use of different scale rules. Most scaling of sawlogs in this country is done with the Doyle, Doyle-Scribner, Scribner, Scribner decimal C, International, and Spaulding scale rules. In the United States Forest Service, the Scribner decimal C rule is the standard board-foot rule and the International 1/4-inch saw kerf rule may be used. The Doyle-Scribner rule is standerd for most private operations in the South and is used in some other regions. The Spaulding rule is the statute rule for California, and is widely used elsewhere on the Pacific Coast. The International 1/4-inch saw kerf rule is gaining favor with private operators in some regions.

A few examples are given in table 1 to show the wide differences in the results obtained with some of the scale rules for logs of certain sizes. It will be seen that for a 10-inch log the Doyle rule gives a scale only about 55 percent as great as that given by the International rule, 60 percent as great as that given by the Scribner decimal C rule, and 72 percent as great as that given by the Spaulding rule. For logs from 14 to 36 inches in diameter, approximately the same results are obtained with the Scribner decimal C rule as with the Spaulding rule.

The Scribner log rule is a diagram rule that assumes 1-inch boards at least 4 inches wide and a 1/4-inch saw kerf. It does not take into account the taper of logs. It gives a large overrun for small logs and for logs longer than 16 feet. The Spaulding rule, also, is a diagram rule. It makes no allowance for taper and makes a uniform allowance for total waste regardless of width of saw kerf. The Doyle and International rules are based on formulae. The Doyle rule greatly underscales small logs and overscales large ones. The International rule assumes a taper of 1/2 inch for each 4 feet of length. This is about right for a large number of species, but is too much for some species like southern pines and not quite enough for some of the hardwoods. The International 1/4-inch saw kerf rule is the most accurate of all the rules listed here. For the United States as a whole, it gives results closely approximating the green-chain lumber tally. When estimates are made by this rule, however, mills in the Inland Empire get an overrun for white pine and mills in California get an underrun for ponderosa pine and sugar pine.

Table 1. --Volume of logs of various sizes as measured by four scale rules

Size of log		Volume by different scale rules			
Top diameter (inches)	Length (feet)	Doyle	Scribner decimal C	Spaulding	International ¼" saw kerf
		Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.
10	16	36	60	50	65
14	16	100	110	114	135
16	16	144	160	161	180
20	16	256	280	276	290
24	16	400	400	412	425
36	16	1,024	920	950	980

Differences in scaling practice between different operators cause differences in scale of net volume amounting in extreme cases to 10 percent. Many operators scale to the nearest inch, others round down to the full inch; the resulting difference amounts to from 5 to 7 percent. In the South, where the Doyle-Scribner rule is commonly used except for small logs, and in some other regions, it is standard practice to scale on the narrow diameter and round down to the full inch. In the case of small logs sometimes the bark is scaled or a certain volume per lineal foot is allowed. Some scalers do not make deductions for sweep unless it is extraordinary, others make allowance for all sweep.

The standard scaling practice of the Forest Service is to use the average diameter inside bark rounded to the nearest inch and make deductions for all defects --in other words, to scale on the basis of straight and sound material.

Log Grades

In some regions log-grading rules have been standardized and logs are scaled and bought by grade. This practice has been in effect for many years on the Pacific Coast, is increasing throughout the country, and will probably grow very rapidly. Fair log grades form the soundest basis for determining log or timber value, and should be the standard for buying and selling; but before such a standard can be put into practical application in different regions some simple log-grading rules must be worked out.

These rules will be approximations at best, but if they are applied by intelligent, experienced men they will give reliable averages.

Cubic Foot and Cord

Cubic-foot estimates are usually limited to pulpwood and fuel wood, although wood-utilization practices are broadening out so rapidly in this country that there is no logical reason why all sawlog-size material should be scaled in board feet. One serious drawback to scaling sawlogs in cubic feet has been the impracticability, in many cases, of measuring the middle diameter. The need for obtaining this measurement can easily be eliminated by basing the cubic-foot rule on taper factors to suit the different species. With a cubic-foot rule made on such a basis, the content of a sawlog can be determined by measuring the small end of the log, just as with any ordinary board-foot rule.

The standard cord is a pile of rough or peeled wood 4 by 4 by 8 feet, having a gross volume of 128 cubic feet. A standard cord of rough straight pulpwood cut from a second-growth stand of pine or spruce usually totals from 90 to 100 cubic feet of wood and bark. In private practice the gross content of the cord varies considerably; in some regions it is 128 cubic feet, in some 160 cubic feet, and in others 180 cubic feet. The length of pulpwood varies among different regions. The wood is usually cut 8 feet long in the Lake States, 5 feet long in the South, and 4 feet long in New England.

In a cruise made for pulpwood the cruiser can use volume tables based on cubic feet of wood and merchantable height or tables showing number of sticks per standard cord by diameter class. He must know the minimum tree size and the minimum top diameter. Estimates are often made in terms of cubic feet of rough wood and then converted into cords. If the cubic foot of peeled wood is made the unit of measure the cruising job becomes more complicated, because of the variation in bark thickness between species, between forest conditions, and from place to place. Bark volume is usually a higher percentage of total cubic-foot volume in second-growth stands than in old-growth stands. In certain diameter classes the bark percentage of a given species may vary as much as 10 percent between regions. Unless local volume tables are constructed, it is necessary to make a very thorough check of bark thickness.

Volume of peeled wood in cords can be estimated satisfactorily by the use of volume tables for rough wood if the percentage of bark, by diameter class, is known for the various species. It is better, however, and greatly facilitates compilation of the estimate, to convert the tables to cubic feet of peeled wood or construct local volume tables on that basis.

Other Units

Cunit

The cunit, 100 cubic feet of solid wood, is the standard unit of cordwood measure in some parts of Canada. It is a very fair and sound unit of measure, and is entirely practical for application to either pulpwood or sawlogs. Measurement in terms of solid wood content is basically sound regardless of the purpose for which the material is to be used, except for such products as poles, piling, and hewn ties. Adoption of the cunit would put the measurement of pulpwood on a uniform basis for the entire country.

Poles

Quantity of poles is expressed in number of pieces. Poles are tallied by breast-height diameter and length and, in some regions, by class. To make a reliable pole estimate, a cruiser must be thoroughly familiar with the pole specifications and grading rules. If a high degree of accuracy is required in the cruise it becomes necessary to examine carefully each individual tree on the sample plots or strips. Pole grade can be determined by reference to standard pole specifications. Important factors are rate of taper and straightness.

Piling

Quantity of piling is expressed in lineal feet or in number of pieces by length. The specifications for piling are usually less rigid than those for poles. Many trees will make piling that because of defect or poor form would not make acceptable poles, and piling is made from a greater number of species than poles. Cruising for piling, as for poles, requires much experience and good judgment.

Ties and Posts

When a cruise is made for a sawed-tie operation, usually the timber is estimated in board feet, log scale, the average number of ties per 1,000 board feet is determined, and the board-foot estimate is converted to number of ties. For a hewn-tie operation the estimate is ordinarily expressed in number of pieces, by tie grade. Tables of taper by diameter and height class are very valuable for this type of cruising.

Posts are of less value than other products, except in such species as juniper and eastern red cedar. They are usually 6 to 8 feet long. A bolt having a diameter of more than 7 inches is usually split into two or more posts. The numbers of posts that can be cut from trees of different dimensions are usually estimated from specially prepared tables.

CHAPTER 3. RUDIMENTS OF SAMPLING IN TIMBER CRUISING

Cruising as a Sampling Process

All timber cruising, except 100-percent estimates, is based on some form of sampling. A sample, in the broad sense, is a part of anything presented as evidence of the quantity and quality of the whole. Plots or strips well distributed over the whole of a tract represent the characteristic variation of timber volume within the tract. If properly used, they yield reliable information. The cruiser's chief aim, of course, is to make his timber estimates reasonably correct. Learning how to take reliable samples on which estimates of timber volume may correctly be based, and how to make accurate observations on these samples, is a matter that greatly concerns him.

Most of the outstanding authorities on the theory of sampling maintain that sampling error cannot be computed satisfactorily unless the samples are taken at random. In ordinary cruising, however, random sampling is impractical, and mechanical sampling is substituted. In mechanical sampling, cruise or travel lines are run equal distances apart and sample plots are taken at regular intervals along these lines. For example, cruise lines may be run 10 chains apart and ¼-acre sample plots taken 2½ chains apart along them. This procedure usually gives a closer estimate than random sampling. Theoretically it does not permit determination of the true sampling error, but the error computed from the mechanical sampling may not differ greatly from the true sampling error.

Every timber cruiser knows that the volume of timber varies from one acre to another. He knows, too, that there are many reasons for this variation, such as differences in productivity of site, in stand composition, and in the age, density, and quality of the timber, disturbances caused by cutting and fire, breaks in the topography, and proximity of streams, lakes, and roads. Walking through the woods, he has observed that forest cover type and stand conditions are hardly ever uniform throughout the area covered by a cruise, and that sometimes a condition is segregated on small scattered areas like spots on a leopard skin. He knows that he cannot pick an average acre representing a true cross section of all timber types and timber conditions present on a given area of as much as 5 acres. As a matter of fact, the existence of such a true average acre is always unlikely. Ideally, a cruise would consist in taking a complete record of timber volume, perhaps a count of all trees by size; but, because of expense, this ideal can be realized only in special cases and for comparatively small areas. For these reasons, the timber estimator must rely on some method based on intensive observation of sample areas.

Cruising, both in methods of obtaining tally records and in methods of analyzing records and judging the reliability of final results, is a statistical process and should be recognized as such. Timber estimators have used the general principles and the methods of statistics for many years, although perhaps without realizing it. During the past 10 or 15 years, many practical investigations have been made to clarify the principles underlying estimates of the extent and volume of forest stands. Such investigations were made in connection with national forest surveys in Norway, Sweden, and Finland. Several studies of the errors of sampling have been made in the United States since our Nation-wide Forest Survey was begun in 1930.

Common sense tells us that the greater the proportionate area of the sample plots examined, the greater is the accuracy that may be expected from the cruise. It stands to reason also that samples, aside from being numerous, should be distributed over the area so as to "catch" all conditions, and in such a way as to give every part of the tract an equal and independent chance of being represented. Any particular timber condition should be represented in the sampling in the proportion in which it occurs over the entire area.

The general distribution of forest conditions should be determined in advance. Usually cruise lines should be run across the drainage or other natural features, as this greatly reduces the probability of overestimating the prevalence of conditions that occur along these topographic features in long, narrow strips or bands. If the timber occurs in irregular patches scattered promiscuously over the area, sampling should be more intensive than it need be on an area where the distribution of timber is fairly uniform. Large patches are likely to have proportionate representation in any sampling based on running a set of lines over the whole area at uniform intervals, but small patches are likely to be missed. The smaller they are, the greater the chance that they will be missed.

To illustrate the theoretical background of timber estimating as a sampling process, let us assume that an estimate is to be made of the merchantable timber on a given section (640 acres) of land. Having made a preliminary examination of the area, the cruiser decides to make a 5-percent cruise by taking eight 1/4-ecre sample plots in each of the 16 forties. He runs lines in cardinal directions 20 chains apart, and takes 1/4-acre sample plots at 2½-chain intervals along these lines. He records volume separately for all 128 plots and from the records determines the general variation in volume from one end of the section to another. The expectation, naturally, is that the average estimated volume per 1/4 acre for the 128 plots used will closely approximate the average volume per 1/4 acre for the entire tract. Multiplying the average volume per plot by 2,560, the total number of quarter acres, or multiplying the total volume on all plots by 20, will give the estimated volume for the entire area. The accuracy of the cruise can be determined by comparing its results with the actual volume of the material cut, or with the volume obtained by a 100-percent cruise. If use were made of a greater number of plots, properly distributed, this would increase the probability that the true volume would be estimated closely. By the law of averages, errors compensate each other in the long run. The percentage of error for the total volume of the entire 640 acres is almost certain to be much smaller than the percentage of error for the volume of a part such as a forty.

A description of various methods of cruising is given later. Here it will suffice to say that perhaps the most convenient and practical method is use of sample plots mechanically selected. This consists in taking a large number of sample plots, containing 1/2, 1/4, or 1/5 acre each, at some regular interval over the entire area of the timber to be cruised. For these plots a complete record is made of all information desired, such as a tally of trees by breast-height-diameter class and by species and merchantable height. From plot records, volumes are computed for the area actually examined and for the entire area of the tract.

Intensity of Sampling Necessary

What intensity of sampling is required in a given instance depends upon the purpose for which the cruise is made, the value of the species involved, and the variability of the stand. A 10- to 20-percent cruise by 40-acre divisions is considered by most timber owners, loggers, and lumbermen to be sufficiently accurate for all practical purposes in most types. The 10-percent cruise is most common except on the Pacific Coast, where the 20-percent cruise is standard practice for private cruising firms. For certain valuable types and for certain forest conditions, nothing short of a 100-percent cruise is reliable or satisfactory, particularly for small areas.

If a reliable cruise by 40-acre subdivisions were desired for an area in Coos County, Oreg., that has on it some Port Orford cedar, a 100-percent cruise should be made of the Port Orford cedar. If, on the other hand, it were desired to determine how much Port Orford cedar there is in the entire county, a careful cruise covering 5 percent of the county's area, consisting of samples properly distributed, would be sufficient. If an accurate cruise of yellow poplar, white ash, and black cherry were desired for an area of 160 acres in a stand of old-growth mixed hardwoods in the Great Smoky Mountains of Tennessee, it would be necessary in some cases to make a 100-percent cruise of these species, because yellow poplar in this region occurs in groups in the coves or as large scattered individuals along the creeks and lower slopes. As a rule white ash and black cherry, also, are widely scattered and would require a full count on such a small area. On the other hand, if a reliable estimate of the volume of these valuable species were desired for the entire Great Smoky Mountain region, a cruise of 5 percent or less would probably give satisfactory results.

Idaho white pine, usually very valuable, should be sampled with a much higher degree of intensity than would be necessary for hemlock, larch, and Douglas fir in the same territory, where they have very little value. A cruise that would check out within 5 percent might be considered necessary for the white pine, but a cruise within 15 to 25 percent of the actual volume might be satisfactory for the larch and Douglas fir.

Comparatively meager sampling would be satisfactory for extensive stands of second-growth Douglas fir and hemlock on the Pacific Coast, for pure ponderosa pine in Arizona, New Mexico, California, Oregon, Washington, Idaho, and Montana, for second-growth southern pine in the southern Coastal Plain region, or for red spruce in New England. In examples such as these, in which the species do not differ greatly in value or only one species is involved and the stand is fairly uniform, a cruise of as little as 5 percent gives entirely satisfactory results for areas as small as four or five sections (2,500 to 3,000 acres).

In the forest survey of the Douglas fir region of western Oregon and western Washington, made as a part of the Nation-wide Forest Survey begun in 1930, it was determined that a 5-percent cruise was practically as reliable as a 10- or 20-percent cruise for 200 forties of Douglas fir selected at random in any county in the region. The 5-percent cruise was inadequate, of course, for individual forties. Most lumber companies in that region consider a fairly close estimate by 40-acre tracts necessary for efficient planning of their logging operations. If a 20-percent cruise will give satisfactory results for a completely timbered 40-acre tract, a 5-percent cruise will give more accurate results for a completely timbered section on which conditions are practically the same as on the forty. If the 1/4-acre-sample-plot system is used, 32 samples will be obtained on the 40-acre tract and 128 samples, or four times as many, on the section. From 128 samples, taken under the same conditions and representing as good distribution as the 32 samples on the forty, a more reliable estimate will be obtained for the section than for the forty.

The exact intensity of sampling required to ensure a certain degree of accuracy cannot be calculated until it is definitely determined how variations in forest conditions existing on the area affect the average volume per acre (see part II). This is especially difficult when a large area is involved. In most cases, cruisers depend on their judgment. An experienced cruiser can usually tell, on the basis of a preliminary investigation of a tract, approximately what intensity of sampling will be required for a reliable estimate of the volume.

Probably the simplest and most practical way for the inexperienced man to train himself to determine what intensity of sampling is necessary under different conditions is to select several areas of, say 40 to 160 acres each, in different localities and types and representing widely different conditions, and make a 5-percent, a 10-percent, a 20-percent, and a 100-percent cruise on each area. By analyzing the resulting information, the intensity of sampling required to give any desired accuracy of results may be closely approximated for a tract of any type, condition, or size.

Reliability of Sampling Results

No matter what we measure, we must always take into account the likelihood of errors. If we measure the height of a 60-foot standing tree many times, say with the Abney level, our results will disagree sometimes by more than 3 feet. Most of the measurements, however, will cluster within a 1-foot range of difference. Small errors will occur very often, large errors less often, and extreme errors very rarely. When a large number of independent cruises of the same intensity are made on the same tract by cruisers of experience and established ability the results are found to differ, in some instances widely but on the whole only slightly. If all the men are equally competent, and use the same cruising standards, the extent of the variation indicates the reliability of the sampling process, or the chance that an error of given magnitude will be made.

When we wish to obtain some idea of the accuracy of a measurement we have made, we usually repeat it several times. From the distribution of the results of the repeated trials, we next determine what percentage of all trials may be expected to fall within any given range on either side of the average.

If a tract to be cruised has an extent of, say, 40, 160, or 640 acres, the simplest way to compute the error of sampling is as follows:

1. Make out a tabulation showing the volume on each sample plot. Determine the total volume on all plots by simple addition. Divide this total by the total number of sample plots taken, and thus obtain the mean or average volume per plot.

2. Determine the difference between each individual plot's volume and the average.

3. Square each individual difference, and add up the squared differences. Divide the sum by the number of samples taken less one.

4. Extract the square root of the result. This is the standard deviation.

5. Divide this figure by the square root of the number of samples taken, and the result is the approximate standard error of sampling. If the sampling has been done carefully, and the samples are representative of the entire area, the chances are that two times out of three the cruiser's estimate of volume per plot will be within that range of error, either plus or minus.

Table 2 illustrates the preliminary steps in computing the standard error of sampling. The total volume on the 16 sample plots is 128 M board feet. The average volume per plot, therefore, is 8 M board feet. The differences between individual plot volumes and the average are shown in column 3, and the squares of these differences are shown in column 4. The squared differences total 172 MM board feet. Dividing this total by the number of samples taken less 1, or 15, gives 11.47 MM board feet. The square root of 11.47 MM board feet is about 3.4 M board feet, the standard deviation. Dividing 3.4 M board feet by 4, the square root of the number of samples taken, gives about 850 board feet, which is the standard error of sampling. Dividing 850 board feet by the average estimated volume per plot, 8,000 board feet, we find that the standard error is about 10.6 percent.

If an accurate estimate by forties were desired, this sampling error would not be considered satisfactory. The sampling error for the entire tract should not ordinarily be more than 5 percent in estimating volume of low-value species, and in estimating volume of valuable species it should not be more than 2 or 3 percent.

Table 2.--Sample computation of standard error of sampling in 10-percent cruise of a 40-acre tract with 1/4-acre plots

Plot (number)	Volume	Deviation from average	Deviation squared
	M board feet	M board feet	MM board feet
1	9	+1	1
2	5	-3	9
3	16	+8	64
4	12	+4	16
5	5	-3	9
6	4	-4	16
7	3	-5	25
8	9	+1	1
9	7	-1	1
10	6	-2	4
11	10	+2	4
12	9	+1	1
13	6	-2	4
14	12	+4	16
15	7	-1	1
16	8	0	0
Total	128		172
1	2	3	4

The error of sampling is inversely proportional to the square root of the number of samples taken. The number of samples required to give an acceptable sampling error can be determined as follows:

1. Determine the standard deviation as just shown.
2. Determine what percentage this is of the average volume per plot.
3. Square this percentage.
4. Square the error percent decided upon as acceptable. For example, if the acceptable error is 2 percent, square 2.
5. Divide the squared value of step 3 by the squared value of step 4, and the result will be the number of sample plots required to obtain the desired accuracy.

The acceptable error is usually set at either one-half or one-third of the maximum error allowed for the estimating job, depending on how much confidence one wishes to place in the cruise.

The method just described will not work for an area of less than a section or for a sampling error of less than 2 percent, unless a correction factor is applied. The method of calculating the proper correction factor for small areas is presented in part II.

A 10-percent cruise of a 160-acre tract on which the variation in the timber is the same as that shown in table 2 gives a sampling error of approximately 5.3 percent; under the same conditions such a cruise of a section (640 acres) gives a sampling error of approximately 2.7 percent. A 10-percent cruise involves use of 64 sample plots on a 160-acre tract, in comparison with 16 on a 40-acre tract. The square root of 16 is 4, and the square root of 64 is 8. Since the sampling error is inversely proportional to the square root of the number of samples taken, the error for the 160-acre tract is one-half of 10.6 percent (the error for the forty) or approximately 5.3 percent.

The cruiser should bear in mind that the standard error thus calculated is only the error of sampling. Inaccuracies in timber cruising may result from errors in volume tables and errors in estimating sample-plot dimensions, tree diameters and merchantable heights, cull, etc. The possibility of errors of these other kinds must be checked by other methods.

In this discussion of sampling timber stands, the writers have tried only to give the cruiser a rudimentary understanding of the process. Many formulas are used to calculate the reliability of timber cruises of different degrees of intensity. Part II of this manual deals briefly, in a more technical way, with the fundamentals of the theory of sampling and with elementary statistical analysis, and lists some of the excellent textbooks available on statistical methods.

CHAPTER 4. METHODS OF CRUISING

Of the several methods of timber cruising, the strip method is probably more widely used than any other in certain regions of the United States--particularly on the Pacific Coast. Until the last 10 or 12 years it was used by the United States Forest Service almost exclusively. It is strongly believed that in general the line sample-plot method is equal or superior to any other method, particularly for beginners. The superiority of this method over others has been demonstrated repeatedly by field tests. What method of cruising will give the best results in a given case depends to some extent on the training and experience of the men who do the work.

Strip Method

In the strip method, narrow continuous strips are run through the tract at regular intervals and the timber on the strips is tallied as a sample of the stand. The most common width of strip in stands of average density is 1 chain, or 33 feet on each side of the travel line. In open stands of ponderosa pine, a strip 2 chains wide is often used. In dense stands of small timber, such as spruce or lodgepole pine, the width of the strip is sometimes cut down to 1/2 chain, or 33 feet. In a 20-percent cruise, ordinarily each forty is crossed four times, in cardinal directions, with parallel strips 1 chain wide and 5 chains apart. In a 10-percent cruise, the distance between the 1-chain strips is 10 chains; in a 5-percent cruise, it is 20 chains.

These advantages are claimed for the strip method:

(1) A complete cross section of the tract is obtained by gridironing from one end to the other.

(2) The cruisers travel through all timber types and measure trees in all sorts of country, good and poor. Timbered areas, open areas, swamps, etc. are taken in the actual proportion in which they exist.

(3) The occurrence, extent, and proportion of the different types of barren and untimbered areas, of water surfaces, and of burns can be determined reliably.

(4) Its use is entirely practical for inexperienced men.

(5) It is a very rapid method.

(6) The systematic location of the strips makes possible the preparation of a type and drainage map.

Disadvantages of strip cruising are as follows:

(1) It is very difficult to estimate accurately the width of the strip unless the center line is definitely marked, and this is not considered practical. In practice, width of strip is usually estimated by eye and is rarely checked by actual measurement.

(2) It is the habit of many cruisers to wait until they get almost under the trees before tallying the heights, and this usually results in an estimate entirely too low.

(3) In stands of large timber the tendency is to include too many trees; a tree 5 or 6 feet in diameter close to the edge of the strip appears to be considerably closer to the center line than it actually is, because the cruiser is looking at the side closer to the center line.

(4) In dense stands of small timber it is almost impossible to make an accurate count of the trees. The cruiser is likely to miss a considerable number of trees or to count some trees twice.

(5) If the line is not chained and the cruiser has to depend on the compassman to determine the distance, the estimate is often materially affected by over- or underpacing, which is difficult to correct. If the compassman happens to pace a few chains over the section line, the error affects all forties.

(6) An accurate check cruise is not practicable unless the original line is marked on the ground. In order to obtain a reliable check, a much larger area must be checked than is necessary when sample plots are used.

(7) The method is not practicable for a man working alone.

(8) It does not lend itself to statistical analysis unless the estimates are kept separate by some uniform unit, such as a 5-chain section.

Line Sample-Plot Method

The line sample-plot method of cruising has been used for a long time and is rapidly increasing in favor, not only in this country but throughout the world. This method was used in the New England States probably earlier than anywhere else in the United States, has long been the standard system of estimating pulpwood in that region, and in fact is practically the only method used there.

Circular plots of 1/5, 1/4, 1/2, or 1 acre are used, according to forest conditions. The 1/4-acre plot is the one most commonly used throughout the United States. The 1/5-acre plot is favored for dense stands in several regions, particularly where a chain is used to determine the distance. Plots of 1/2 acre or sometimes 1 acre are used in open stands such as those of ponderosa pine; elsewhere plots of these sizes, although they may give better results under certain conditions, are seldom used. Whatever the plot size, ordinarily the same percentage of total area is covered as would be covered by a strip cruise.

In cruising by the sample-plot system the timber is usually tallied by breast-height diameter and height to a fixed top diameter, by diameter and merchantable height, by diameter and total height, or by diameter only. In using this system it is very practical, also, to tally by the methods known as logs per tree and logs per thousand, or to tally volume direct.

Advantages of the line sample-plot method are as follows:

(1) If the line is chained, the sample plots are located without bias, and the location of each plot is determined exactly. Consequently, if an intensive cruise is made a reliable representation of all the forest conditions is obtained.

(2) The center of each plot can be definitely marked by the compassman.

(3) The estimator is not hindered by brush and windfalls and other obstacles to the same extent as in strip cruising.

(4) The cruiser can have the compassman tally the timber, measure diameters, or measure out to line trees, regardless of what method is used to determine volume on the plot. This means that the cruiser can devote more time to sizing up diameters and heights of trees than he ordinarily could if using the strip system.

(5) The area of the plot can be determined more accurately than that of a strip, because it is entirely feasible to measure out with tape in any direction from the center of the plot, which is definitely fixed, and determine whether a tree is in or out.

(6) If a stake is set to designate the center of the plot, the checker is certain to take exactly the same trees as the original cruiser. For this reason, the sample-plot system permits a definite and detailed check that is practically certain to reveal any error made by the original cruiser. Strip cruising does not do this unless the center line is definitely marked.

(7) A separate record can be kept of each plot. It is then possible to group plots by forest type and condition, and to reassemble the estimates by section, logging unit, and other land divisions and by cover type.

(8) If the volume estimate for each plot is kept separate the variation from place to place in stand per acre can be shown on the map, which is not practicable if the ordinary strip-cruising method is used.

(9) Cull and breakage can be determined more accurately, because the cruiser has a better opportunity to study the trees and size up all the conditions affecting net volume. Also, he can carefully size up the timber between plots, because he does not have to tally any timber between plots.

(10) Both diameter and merchantable height can be determined more accurately. In ordinary timber the trees near the outside of a 1/4-acre plot are about the right distance away from the center of the plot for sizing up heights.

(11) If distances are paced, errors in pacing do not materially affect the accuracy of the cruise, because the necessary number of plots are taken regardless of such errors.

(12) The method can be used to good advantage by a man working alone.

(13) The data taken lend themselves to statistical analysis, if plot volumes are kept separate.

Complete or 100-Percent Estimate

In most regions of the United States a complete record of all trees of merchantable size on a forest tract is seldom made. Complete, or 100-percent, estimates have probably been made more often on the hardwood lands of the South than in any other section of the country. A considerable portion of the hardwood timberland of the Mississippi Delta and the river bottoms of the South has been cruised by the 100-percent method, known there as the tree-treatment method. Wherever species of high value are involved and the trees of these species are unevenly distributed, a complete count may be necessary for small to medium-sized areas.

Advantages of the complete estimate are as follows:

(1) A complete record of all trees of merchantable size gives the best possible basis for an accurate estimate of total volume.

(2) Cull can be determined more accurately because each individual tree is considered and the cull is usually deducted on the ground.

(3) The quality of the timber can be more accurately determined, because a complete tally can be made by log grade.

(4) Where high values are involved and trees are unevenly scattered over the area, this is the only accurate method of cruising small to medium-sized tracts.

The principal disadvantage of this method is that it is too expensive for large tracts.

Other Methods

Several other methods are used. Some cruisers select what they judge to be average acres at different locations throughout the tract and make a careful estimate of the timber on these selected acres. This method of cruising is rather risky, because average acres cannot be selected with any great degree of accuracy.

If only an approximate estimate for a large tract is required, a rough reconnaissance in which random sample plots composing a very small percentage of the area are taken will give the required information at very small cost, as other methods might fail to do.

Ocular estimates are often made for the purpose of determining whether a detailed cruise is justified. In this type of estimate, usually the cruiser endeavors to determine the quantity of timber on a given watershed within 15 to 25 percent. This method has been employed in many regions in making rough reconnaissance surveys. Some cruisers are able to get very good results in intensive cruises by making ocular estimates of the stand per acre of timberland or even of the volume on an entire forty. If a cruiser works a long time for one company in one locality, through careful comparison of cutting records with appearance of the uncut stands eventually he may become very proficient in judging the stand per acre. This system cannot be used by a beginner, or even by an experienced cruiser in a region with which he is not familiar and in which the stand per acre varies greatly from that of the region where he gained most of his experience.

CHAPTER 5. METHODS OF TALLYING TIMBER

D.b.h. and Logs to a Fixed Top

Tallying timber by d.b.h. and number of logs to a fixed top diameter was practiced by the Forest Service for many years, but in general is not at the present time. It never has been practiced to any extent by private cruising firms. Tallying timber to a fixed top is practicable only for conifers; in hardwoods there is no uniformity as to length between a fixed top diameter and the tip of the tree. It is the opinion of the writers that hardwood volume tables based on a fixed top usually result in erroneous estimates, if applied literally, and so are practically worthless.

One argument for this method was that inexperienced men could more easily be trained to estimate to a fixed top diameter than to a merchantable top diameter. A cruiser can train himself to estimate to a fixed top with a fair degree of accuracy. If a sufficient number of down trees in each diameter class are measured to determine the average length from the fixed top to the tip, and the resulting data are plotted over diameter or a table is compiled showing this length by diameter class, he can check his judgment by measuring the total heights of sample trees with an Abney level, making the proper deductions to reach the fixed top diameter by reference to the curve or table, and comparing the heights thus determined with his estimates. If windfalls are available along the cruise line, he can get a fair check by measuring a large number of these.

D.b.h. and Logs to Merchantable Top

Tallying timber by d.b.h. and number of logs to a merchantable top diameter is becoming more and more the general practice. The Forest Service in most regions now uses this method. Private cruising firms use it in practically all cases in which timber is tallied by diameter class and volume tables are used. It is much more accurate than tallying to a fixed top, particularly for experienced men. It does not require much time to train inexperienced men to do a fair job by this method.

D.b.h. and Log Grade

Tallying timber by d.b.h. and log grade has not been generally practiced. This method, however, is gaining popularity very fast. It is used to some extent in the South, the Northeast, the Lake States, and the Pacific Northwest. It gives the best possible index of value, and will certainly be used much more generally in the future than it has been in the past. In a cruise of a large tract, reliable information on the quality of the timber can be obtained by grading a few hundred trees of each species, selected at random.

D.b.h. and Total Height

D.b.h. and total height are used in some regions for tallying pulpwood. They are so used by the Forest Service in the Northeast. Sometimes board-foot volume tables are constructed on this basis. In such cases the timber is tallied by total height or measurements are made, with an Abney level, of the heights of a sufficient number of sample trees to produce a strong curve of height over diameter.

D.b.h. and Merchantable Height

D.b.h. and merchantable height are widely used in the South for tallying pulpwood species. Usually, the timber is tallied by 2-inch diameter class and to the nearest 4 or 5 feet in length; in other words, a record is made of the number of 4- or 5-foot sticks a tree will produce. In trees from 6 to 16 inches in breast-height diameter, the top diameter ranges from 4 to 6 inches and averages approximately 5 inches.

Volume Direct

Direct tallying of timber volume is practiced rather extensively on the Pacific Coast, but is uncommon in any other region of the United States. It is used by some cruisers in ponderosa pine, sugar pine, Douglas fir, redwood, the bottomland hardwoods of the South, and the mixed hardwoods of the Appalachian region. When working in large timber such as Douglas fir, redwood, or sugar pine, the cruiser looks at a tree and estimates that it contains 4,000, 5,000, or 10,000 board feet, as the case may be, rounding off the volume to the nearest 1,000 feet. This method of estimating volume may not appear to the average forester to be scientific. Certain exceptionally able cruisers on the Pacific Coast make use of it with good results.

Cruisers employing this method usually make frequent checks of their estimates of the volume of individual trees. Most of those on the Pacific Coast carry taper tables and refer to them whenever they consider a check necessary. These tables show volume inside bark for trees of different diameters and merchantable heights according to taper. When a check is desired on the estimate for any individual tree or for a sample plot, the cruiser measures the tree or trees with a diameter tape, estimates the thickness of the bark, the taper, and the number of logs, estimates the volume, and then refers to the table. Other cruisers carry a card showing the volume of the average log in different-sized trees. Multiplying this volume by the number of logs in the tree gives a scale of the tree that serves as a good check on the cruiser's judgment. Others who are thoroughly familiar with the variations in volume due to variations in site quality memorize the volumes shown by the volume tables for the individual diameter groups, such as 30 inches, 36 inches, 42 inches, and 48 inches, for average site quality, and use them as a check.

The best test of any cruise is a reliable cutting record.

Top Diameter of First Log and Taper

Tallying by top diameter of first log and taper is practiced both on sample plots and on strips. This method of determining the board-foot volume of standing trees is preferred by some of the most able hardwood cruisers in the United States. It is probably more common in the bottomland and other hardwood sections of the South than anywhere else in this country. A cruiser using this method makes an ocular estimate of the diameter inside bark of the top of the first 16-foot log, and estimates the taper for each additional log. If a log length other than 16 feet is used, this length is clearly indicated in the records. It is a well-established fact that the taper of the bottomland hardwoods of the South averages fairly close to 2 inches per 16-foot log. Some species have less taper than this, others have more. If a material variation from the 2-inch average is observed in any particular species or in any particular diameter or height class, an adjustment is made by adding to the total volume or deducting from it.

The top diameter inside bark of the first log cannot be estimated very accurately, but if the cruiser is good on judging diameters and has a knowledge of bark thickness he generally gets good results even though some of his estimates for individual trees are considerably too high and others are considerably too low. These errors tend to compensate in the long run. Cutting records have shown that many cruises made by this method were remarkably close.

D.b.h., Merchantable Height, and Total Taper

Some cruisers in the South tally timber by d.b.h., merchantable height, and total taper. When this method is used, records are made of the estimated diameter outside bark 4½ feet from the ground, the estimated merchantable length, and the total estimated taper from outside bark at breast height to inside bark at the top of the last log. If a 20-inch old-growth longleaf pine were recorded as having a merchantable length of 64 feet and a total taper of 8 inches, this would mean that the top diameter inside bark of the last log was estimated at 12 inches. Cruisers who use this method carry tables showing what percentage of the total taper is represented by each log. In the case just given the first log would have about 40 percent of the total taper, the second about 17 percent, the third about 20 percent, and the fourth about 23 percent. The top diameter inside bark of the first 16-foot log would be 16.8 inches, that of the second 15.4 inches, and that of the third 13.8 inches. If each of these diameters were rounded off to the nearest inch, the Scribner decimal C rule would give this tree's volume as about 510 board feet.

In 4-log trees the taper in the first log is from 37 to 40 percent of the total. The reason why the first log has such a high percentage of the total taper is that the diameter at breast height is taken outside the bark.

There are cruisers in the South who, by this method, can estimate the volume of 100 standing trees within 2 or 3 percent of actual scale. This method is very rapid. Many years of experience are required, however, before the cruiser begins to feel confident about the results he can obtain in this way.

Logs per Tree and Logs per M

Tallying by logs per tree and logs per 1,000 board feet was widely practiced in several parts of this country 20 or 30 years ago, with both the plot and the strip system; it is still used in some regions, but only to a very limited extent. The number of trees on the plot, the average number of logs per tree, and the estimated number of logs per 1,000 board feet are recorded. From this record the volume can be computed very rapidly.

The method most commonly used in the early days for training cruisers to use this system was to have them scale logs in the woods. Often they would scale logs during the winter and cruise timber during the summer and fall. By carefully studying the timber on the operation on which they were working, and by determining from their scale record the number of logs per 1,000 board feet for different species, different sizes, different age classes, etc., they developed ability to obtain satisfactory results in this way.

Inexperienced men cannot cruise by this method unless they have some rule to serve as a check on the ground. Some cruisers use volume tables for such a check. After estimating all the trees on certain plots, by reference to the volume tables they determine approximately what their error is. Others carry a card showing number of logs per 1,000 board feet for different diameter classes. The most important thing to keep in mind is to classify the timber by size. Reliable results cannot ordinarily be obtained if, for example, 16-inch trees are growing among 30- or 40-inch trees. Where a wide range in diameter occurs, the general rule is to consider two or three broad size classes. If the timber is even-aged and fairly uniform in size, frequently the cruiser selects from each sample plot the tree that in his opinion represents the average for the stand and multiplies the volume of this particular tree by the number of trees on the plot for a check on his estimate.

The advantage of this method, if sample plots are used, is that the volume on each plot can be shown separately by species.

CHAPTER 6. PRELIMINARIES TO CRUISE

Specifications

Definite specifications should be established for each cruising job. This is the only way to obtain uniform results in different cruises. Some of the items that should be specified are species to be utilized, minimum size of trees to be cut, minimum diameter of utilization, and standards of merchantability for trees and logs. Practices in regard to these matters are discussed in chapter 1. The limit of merchantability can be identified for all practical purposes as that represented by the average utilization practices of good operators in each region. The percentage of defect permissible must be left to the judgment of the cruiser in individual cases, but a broad general rule should be established for each cruise. The Forest Service usually requires that a tally be made of all cull trees; in private cruising a tally of cull trees is not ordinarily required.

Standards of Accuracy

Standards of accuracy should be established for all intensive cruising jobs. This keeps the cruisers on their toes and makes them more careful and scrupulous in their work. The standards of accuracy should be reasonable, that is, readily attainable by careful work.

Net Volume by Species

The volume estimate for an individual species that makes up 75 percent or more of the total volume should check within 5 to 8 percent. For a species represented only by single trees scattered here and there no percentage standard of accuracy can be set. If the strips or plots are not definitely marked on the ground it is not fair to establish a standard of accuracy for scattered species, unless a tree count is made.

Net Volume of All Species

It is believed that under ordinary conditions the net volume of all species should check within 5 percent. If sample plots are used and if these plots are definitely marked, the gross volume should check within 2 or 3 percent.

Organization and Instruction of Crew

Cruising instructions usually cover in detail the size of the crew and the duties of each member, procedure on strips or plots, determination of the limits of merchantability, determination of heights, number of trees needed to check diameter and height estimates, and determination of cull factors and breakage. Most commonly, each crew consists of two men. One man acts as compassman and mapper, the other as estimator. If information on growth and age classes is required, a 3-man crew can work to better advantage. The third man bores the sample trees and records the age, radial growth, etc.

If the timber to be cruised is second-growth pine in the South or second-growth spruce in New England, men with little experience can be used, because the defect does not ordinarily exceed 5 percent and the cruising job can be made largely mechanical. Any bright forest-school student with a real interest in cruising can be trained in a very short time to do just as good a job of determining the gross board-foot or cubic-foot volume of such timber, if reliable volume tables are available, as a man who has had 50 years' experience. If the timber is old-growth cypress in southern Florida the cruising job requires experienced men thoroughly familiar with local conditions, because in some cases the cull runs as high as 50 percent. The same is true of some north Idaho stands of old-growth white pine more than 250 years old, and of old-growth Douglas fir in some parts of the Cascade Range in Oregon.

For cruising timber of particularly good quality and of high value, a man of long experience, good judgment, and known dependability is needed. If the timber is of low value, like western larch and Douglas fir in northern Idaho, which often have a stumpage value of not more than 50 cents per 1,000 feet, log scale, an error of 15 to 25 percent in the cruise would not be very serious, and the cruising can be entrusted to a beginner.

Men thoroughly experienced in the region in which the cruise is to be made do not require training as a preliminary to a cruise, unless they are unfamiliar with the specific methods to be employed. They should always be instructed as to the cruising procedures and standards of accuracy. Other men require training. If the volume table used is based on a merchantable or usable top, it is necessary that the men be trained to recognize this point. For this training beginners can visit logging operations, or an expert can point out to them the actual limits of merchantability. The greatest need is for training in applying cull and breakage factors. No simple rules can be given for determining these factors. Knowledge of cull, breakage, and sweep and the lumber losses they cause can be acquired only through experience and careful study of logging and milling operations.

If inexperienced men are used, and the volume tables are not based on net scale, it is best to make the cruise in terms of gross volume and the chief of party should estimate the cull and breakage.

The common belief among timber cruisers and others that it takes years and years to develop the ability to determine the gross volume of standing trees is founded upon improper methods of training. With the exception of knowledge of the losses due to cull, breakage, and sweep in different species and different regions, quality of timber, and log grades, ordinary timber cruising requires no skill that cannot be acquired in a few weeks of intensive training by any forester who has natural talent and who earnestly desires to become proficient in timber cruising. Reliable results from mechanical methods of estimating timber depend largely upon accurate measurement of diameters and heights and application of reliable volume tables. This does not require anything more than careful, conscientious work.

Experience in training crews has shown that the men whose mental faculties have been best developed by education, close observation, and study of fundamental principles and methods make the best timber cruisers, provided they have natural inclination and liking for the work. An untrained or uneducated man starts out with a big handicap.

It is believed that men can be trained in the principles of ordinary timber cruising with better results and in a shorter period by using sample plots than by any other method. If this method of training the crew is used, it is recommended that the chief of party proceed as follows:

1. Establish a number of 1/4-acre sample plots.

2. Designate the center of each plot by setting a stake about 3 feet high.

3. Carefully measure the diameter and the merchantable height of all merchantable trees of sawlog size on the plot. In some cases it may be necessary to measure also the trees below sawlog size.

4. Record the diameters and merchantable heights separately by species and 2-inch diameter class.

5. Mark all trees on the plot with a bark scratcher, as they are tallied.

6. Apply a volume table, based on d.b.h. and merchantable height, that is known to be accurate.

7. Keep a separate record of all measurements and volume for each plot.

8. Estimate and record the cull, separately for each plot.

When this work has been completed on the sample plots by the chief of party, each man who is to be trained should go through the same procedure independently, with the exception of estimating cull. The results should then be compared and all errors discovered. The particular sources of error can also be determined. If there is a wide difference in results, the man responsible for the training can go back over the sample plots with each individual cruiser and definitely point out the sources of errors. If this is repeated several times, it will be found that all men who are seriously interested in the work are making rapid progress. The next step is to have each cruiser lay out a series of plots, measuring the radius of each, measure all trees, and estimate gross volume. This work should be checked by the trainer. The third step is to have each cruiser lay out a series of plots, marking the center of each plot, and estimate by eye the radius of each plot and the tree diameters and merchantable heights. The object of this third test is to develop speed. From 30 to 50 sample plots should be laid out by each man, so that he may have the benefit of compensating errors. The trainer should check this work by measuring the diameters and merchantable heights of all trees.

Intensive training such as that just outlined makes it possible to determine whether any members of the crew cannot satisfactorily qualify for the cruising job.

Regardless of the training method used, the men should invariably be required to compute the volume of each sample plot while on the ground. In this way the beginners develop judgment of timber volumes per acre or volumes of individual trees.

In the old days before there were any volume tables, taper tables, calipers, diameter tapes, or Abney levels, a timber cruiser needed several years to acquire the same knowledge of gross tree volume that he could acquire now in a few months. On the other hand, acquiring information on woods cull, breakage, mill cull, quality of timber, log grades, and lumber grades requires as much time now as it ever did.

CHAPTER 7. FIELD PROCEDURE

Locating Tract and Starting Point

If the tract to be cruised has been covered by a Land Office survey, it is a very simple matter to locate it and determine its approximate extent. If the tract has been covered by any type of reliable survey and the lines can be found, location is simple. The cruiser should have a map showing the general lay of the land, the water courses, and the ridges. If no map is available he should make a preliminary examination of the area for the purpose of obtaining this information. After locating the section corner the cruiser proceeds north or south, east or west, as the case may require, a sufficient distance from it to locate the starting point. If, for example, he intends to make a 20-percent cruise, using a strip 1 chain (66 feet) wide, he paces or chains along the section line a distance of 2½ chains from the section corner.

In unsurveyed country, if an accurate cruise is required it is necessary in most cases to locate the boundaries of the tract by running base lines and control lines, and if high values are involved it may be necessary to run a closed traverse around it. If the tract is inaccessible, if the prospect of operation is long deferred, or if the timber is of low value, exact location and accurate figures on extent are less necessary. Stations are set designating the location of each cruise line, and thereafter the procedure is the same as in surveyed country.

Procedure in Strip Cruise

From the starting point, in a strip cruise, the cruiser runs his line, usually in a cardinal direction, until he reaches the opposite side of the section, and checks into the section corner, usually tallying the timber on the strip by species and 2-inch diameter class. This finishes the first run. If the course of the first run is north on the east side of the section, for a 20-percent cruise he offsets 7½ chains from the section corner, or 5 chains west of his first cruise line, and this marks the beginning point of his second line. He then proceeds south 1 mile to the section line. This procedure is continued until he has run 16 strips across the section.

It is very important that the strips be so located as to cross the water courses and ridges at right angles, as nearly as is practicable. Heavy stands often occur on narrow strips along creeks and draws. If cruise lines are run parallel to these strips or bands of heavy timber, obviously, much too high or much too low estimates may be obtained for small units.

In timber stands of average density, a 1-chain strip is customerily used. In dense stands of small timber such as spruce or lodgepole pine, it is recommended that the width of the strip be cut down to 1/2 chain, and that the trees be taken all on one side of the line. In open stands such as those of ponderosa pine, a strip 2 chains wide is often used. The distance between strips depends largely on the value of the species involved and the size of the area to be cruised. If a 1-chain strip is used, for a 10-percent cruise the lines are run 10 chains apart and for a 5-percent cruise they are run 20 chains apart.

If a reliable map showing types, age classes, and site quality is available, the cruising can be planned much more efficiently. The cruise lines can be laid in such a manner that all types and age classes are adequately sampled. Availability of a good type map reduces the quantity of cruising necessary to a minimum. In case of a large area of one type and age class, such as often occurs in some regions, the cruise lines can be run at wider distances without lessening the reliability of the results obtained, unless an estimate by 40-acre subdivisions is required.

In surveyed country, distances may be either paced or chained; in unsurveyed country they should be chained, especially if the control lines are more than 2 miles apart.

The chain most commonly used is a 2-chain tape with an additional graduated length, called a trailer, to allow for slope corrections. Even if a pocket compass is used to run the line, it is recommended that the cruiser carry a Jacob's staff to mark the center of the plot. Usually a stake is set to designate the plot center.

If the compassman tallies the timber the cruiser has more time to size up diameters, heights, defect, etc.

A helpful rule for beginners is to tally the trees on only one side of the travel line to some particular point or individual tree that is easily identifiable, then change to the opposite side of the line. This reduces the probability of missing any trees, or taking any trees twice. Another rule is to look ahead and observe changes in height. If the cruiser looks ahead 100 or 200 feet for the purpose of sizing up the timber as to height, instead of waiting until he gets under the trees, he makes much more accurate estimates, especially in timber running from four to six 16-foot logs per tree.

Procedure in Sample-Plot Cruise

If a 20-percent cruise is desired and 1/5-acre plots are to be used, four lines are run across each forty, usually in cardinal directions, and sample plots are taken at 2-chain intervals. This gives 10 sample plots each time a forty is crossed, or 40 sample plots for the four runs. The first plot is taken 1 chain from the beginning point, and thereafter the end of each 2 chains is the center of a plot. It is better to stagger the plots, by shifting the spacing 1 chain on the alternate lines. If 1/4-acre plots are used for making a 20-percent cruise, the same number of lines are run but the plots are taken at intervals of 2½ chains instead of 2 chains.

A type map serves as an aid in timber cruising by the sample-plot method because it automatically divides the area into parts that are more homogeneous than the whole. Having definitely calculated the proportionate extent of different forest types from the map, one may take sample plots proportionately from each of the forest types indicated on the map. If, for example, a given type occupies 20 percent of the total area, and it is planned to take altogether 1,000 sample plots, 200 sample plots should be taken in this particular type. If the degree of variation is fairly constant for each of the different forest types, the error is likely to be reduced by thus taking proportionate samples.

The sample plots should be selected within the area of each type at random, in order to fulfill the condition that each division of each type area shall have an equal chance of being included in the sample. For very intensive work, as is explained in part II, the area of any given type may be subdivided into a number of small units and a few sample plots may be laid out at random within each of these. If areas under consideration are very large a series of lines may be run at random and a series of sample plots taken at equal intervals along each line. On the other hand, if there is definite assurance that the forest type map is accurate, showing homogeneous conditions, not much violation of the theory of sampling is involved in running the sample lines in the usual systematic manner, across the main topographic features. In many cases accuracy is determined in larger measure by intensity of cruise than by arrangement of plots.

While the type map will be used to determine the areas of different forest subdivisions, the sample plots will furnish all other information for the work of timber estimating.

In many parts of the United States, including the Lake States, New England, and the Appalachian region, in a 10- or 20-percent cruise it is often possible to use a small tree to designate the center of the plot. If the nearest tree is not more than 10 or 15 feet from the center of the plot, it can be taken for the plot center. This eliminates the necessity of setting a center stake, and is accurate enough for all practical purposes; it is somewhat better, however, to use the exact plot center. If the plot center is thus shifted, in proceeding to the next plot the cruiser should use the original plot location, not the tree, as his starting point.

The dimensions corresponding to different plot areas, both circles and squares, are given in the appendix.

The circular plot is favored over the square or the rectangular plot, because it can be laid out more quickly.

When a circular sample plot has been established, the cruiser selects as his beginning point some object such as a rock, a windfall, or a particular standing tree that can easily be identified at the completion of the count. Starting the count from this point, he proceeds in a clockwise direction until he has tallied the timber on the entire plot. If the line is chained and work of a high degree of accuracy is desired the cruiser should instruct the compassman to start at the forward end of the chain and proceed in a clockwise direction until he has measured and tallied all the trees. In this case the cruiser remains at the plot center and records the trees as they are called and marked by the compassman. As the compassman measures each tree he marks it with a bark scratcher, on the side facing the center of the plot, so as to avoid missing any tree or counting any tree twice. When uncertain whether a tree is in or out, he measures out to it. A 5-percent cruise made in this manner ordinarily gives better results than a 10-percent cruise in which the diameters of the trees and the radii of the plots are estimated.

Where an intensive survey is made, such as a 10- or 20-percent cruise, it is unnecessary to be so careful to eliminate all doubtful trees, because the greater the number of trees taken the greater are the chances that errors will compensate each other.

The accuracy of work on plots is often affected by forest conditions, weather, size of timber, and other factors. The plot radius does not look the same on a dark, cloudy day as it does on a bright, clear day, and it does not look the same in an open stand as in a stand having a brushy undergrowth. Trees near the boundary of a plot are likely to look closer to the plot center than they actually are in an open stand, and considerably farther from the plot center than they are on a brushy area. For this reason, when a cruiser goes from an open stand to a brushy area, or vice versa, he must do considerably more measuring. Also, in large timber it is necessary to do considerably more measuring than in ordinary stands; large trees look closer to the center of the plot than small trees, because the cruiser is looking at the side of the tree nearer the center of the plot.

Procedure for Complete Estimate

A complete cruise should be made by separate strips, or by small blocks or other units, so that it can be checked. Preferably the crew should consist of a compassman, a cruiser, and a recorder, although a 2-man crew can do the work satisfactorily. The compassman blazes or otherwise marks a line to designate the width of the strip and to serve as a check on what has been included in the estimate; the cruiser calls the timber by species, diameter class, and number of logs; and the third man records these data as called. In some cases all trees are plainly marked immediately after they are estimated. The quality of the timber can be determined by taking, say, every tenth tree of each species as a sample tree and carefully recording the log grades for these sample trees. A few hundred sample trees of each species, if carefully graded, are sufficient to give reliable information on timber quality.

Procedure for Rough Estimate

Assume that a rough estimate is desired for a watershed in the mountainous portion of Montana. Almost everywhere in the timberlands of this area there are high ridges and high peaks which anyone making a cruise of this type can use to good advantage in sizing up the timber or for triangulation purposes in sketching in the types, burns, and other barren areas. The estimator selects a point on a high ridge from which a good view of the timber on the opposite side of the creek or ravine can be had. He then selects a course that, in his judgment, represents about the average run of timber for the area he is viewing. He runs a line on this course and at uniform intervals of from 2½ to 10 chains, depending on the size of the tract, he carefully takes samples of 1/4 or 1/5 acre. When he has completed the run to the top of the ridge on the opposite side, he figures up his estimate. He can then look back and see what the timber looks like on the slope he descended before reaching the creek. Perhaps he originally judged that the timber would average 15,000 board feet per acre, but his detailed tally shows that it averages only 12,000 board feet per acre. Here he learns something by comparison. If he repeats this procedure many times, on many watersheds representing wide ranges in volume of timber per acre, he gradually acquires the capacity to judge timber volumes, and in time trains himself to make very rapid ocular estimates that will be considered sufficiently close for non-intensive surveys.

In flat country it is much more difficult to make a reliable survey of this kind than in mountainous country, because the cruiser does not have the same opportunity to size up the timber from given points. Here it is necessary to follow some system of random or mechanical sampling. By repeated sampling, the cruiser soon learns to make ocular estimates of the stand of timber per acre.

The next thing is to get a rough approximation of the percentage of forest land. If roads traverse the area, the sampling necessary for this purpose can be done very rapidly by using an automobile. If a large area is involved, one way to determine roughly the approximate percentage of forest land and its distribution is to make a few trips over the area in an airplane. The sampling, then, can be adjusted to the actual distribution of the forest land.

Necessary Measurements

No set rule as to measuring width of strip would be suitable for all men. Some cruisers seem to possess an uncanny ability to estimate width of strip accurately, others have to do considerable measuring to get reliable results. If a cruiser is good at judging a distance of 33 feet, in average timber and under average forest conditions his errors compensate each other. A beginner should measure the width of the strip several times when he starts out in the morning, and should measure out in all doubtful cases. He should measure more often in the afternoon, if he begins to tire.

Inexperienced men need to measure the radius of a 1/4-acre plot more often than the width of a 1-chain strip; the distance from the center to the outer edge of the plot is greater than half the width of the strip. After gaining a few weeks' experience, however, a cruiser with a good eye can be fairly certain of all trees that are 1 or 2 feet within the boundary of a 1/4-acre circular plot. Some men need to measure out to the trees near the boundary, others need to measure only to line trees. How much measuring is necessary depends upon the individual's experience and his judgment of distance. Under ordinary conditions and for ordinary cruising, a man who is accurate in pacing distances can satisfactorily determine whether doubtful trees are in or out by pacing out to them.

Probably the most practical way of determining whether a tree is in or out is to measure its diameter, then fasten the tape in the side of the tree facing the center of the plot. If, on a 1/4-acre plot, the distance from that side to the plot center plus half the diameter of the tree is 58.9 feet or less, the tree is in. (Of course, a correction should be made for slope.) A 75-foot tape that the cruiser can carry in his pocket can be used for this purpose. A small horseshoe nail can be attached to the ring in the end of the tape, and by this means the tape can be fastened to the tree in such a way that the ring is flush with the bark.

In ordinary work, the difference between actual and estimated number of trees should not be more than 2 to 3 percent for 200 to 300 trees. On special jobs in which a high degree of accuracy is required, this difference should not be more than 2 percent. On a series of 50 or more plots, number of trees should check within 1 percent.

Heights can be taken with an Abney level. If a sufficient number of windfalls are available close to the cruise line, they afford one of the best possible checks on merchantable height. Learning to estimate heights requires considerably more time than learning to estimate diameters, particularly if the estimating is done to a fixed top diameter for trees of all sizes. Height estimates are the most important part of the cruising job if volume is estimated to a fixed top; they are not so important if volume tables based on taper curves are used.

Diameter measurements are discussed in chapter 9.

Mapping

Topographic mapping in connection with a timber cruise is done according to principles and by procedures amply described in earlier publications. The Abney level can be used. Usually the scale for topographic and other maps made in cruising is from 4 to 8 inches per mile. The writers prefer the scale of 8 inches per mile, because it permits showing more detail.

The mapper should always hold the map "square with the world"; in other words, the top of the map should represent north. He should look in the direction in which he is progressing. He should never map points that he cannot see, except when it is necessary to join type, contour, or other lines.

If no type map is available for use in a 10-percent strip cruise, a fairly reliable one can be obtained by running lines 10 chains apart. This map can then be used to determine type areas by 40-acre subdivisions. When an equally intensive sample-plot method of cruising is to be used instead of the strip method, a more accurate map can be made on the basis of 16 quarter-acre plots well distributed over the forty. In intensive type mapping, distinct forest types and conditions are mapped in units ranging from 40 to 2 acres.

When it is desired to map site quality, the relative productive capacity of different sites, the height of the dominant and codominant trees at a given age is used as an index of this factor.

Determining Volume on the Ground

Gross Volume

The gross volume of a tree is estimated on the basis of three factors: Diameter, merchantable height, and taper. The volume of individual trees can be determined from reliable volume tables or by any of the rules given in chapter 10. Every beginner should become familiar with the volume of trees of different sizes and species as early as possible, and should learn as quickly as possible how to estimate the volume of individual trees and to judge the stand per acre. Men who are not interested in developing this ability will never make high-grade cruisers. Figuring up the volume on a large number of strips or sample plots on different forties is the best training for judging stand per acre. Either 1-acre, 1/4-acre, or 1/5-acre plots are satisfactory for this purpose, but 1-acre plots are somewhat preferable.

Cull and Breakage

How to estimate cull and breakage is something that cannot be learned in a few months or a few years except for certain species in limited regions. There are no rules of thumb for this important element of cruising. Careful study of logging operations is necessary as preparation for estimating woods cull, and careful study of milling operations as preparation for estimating mill cull. Woods cull includes long butts and other sections between the stump cut and the limit of merchantability that are left in the woods because of rot or other defects. Mill cull consists of nonusable portions of the logs sufficiently sound to be taken to the mill for utilization. To develop judgment of mill cull for any species, it is necessary to study the logs at the mill as they are opened up. Much more experience is required for hardwoods than for softwoods.

The quantity of breakage in different species can be determined by scaling cut trees of different species under different logging conditions.

For cruising cedar poles in north Idaho increment boring is essential, because in some localities a large percentage of the poles have butt rot. In a locality where no cutting operations are in progress, it is sometimes advisable for the cruiser to take along as part of his equipment a pair of tree climbers and a climbing belt. By climbing sample trees and boring them, he can determine at what height from the ground the rot runs out. Many very poor estimates have been made of cedar poles in this region because the cruiser had no way to determine definitely the character and extent of hidden defect.

A tally of all cull trees, that is, trees having so much defect that according to the standards set for the cruise they cannot be utilized, shows how much space is occupied by worthless material and indicates about how much sanitation or clean-up work should be done in order to put the area into a productive condition. It has great value where the timber is very defective, as on some Douglas fir timberland in the Cascade Range in southwestern Oregon. Where a large percentage of the timber is so defective as to be unmerchantable, this materially affects the cost of logging. Such a tally is usually required in Forest Service cruises, but seldom in others. It is usually expressed as a flat percentage of total volume.

Checking

Every cruiser in the crew should be checked by the chief of party sufficiently often to make sure that his work is up to standard. The importance of frequent checks cannot be too strongly emphasized. If the original cruise is carefully done it should uniformly check within about 6 percent. Private cruising firms usually require the work to check within 10 percent. If strips are used and they are not so marked on the ground that they can be retraced by the checker, at least one-half section, or 320 acres, should be included in the check. If sample plots are used and are marked with center stakes, 50 to 60 plots are sufficient to determine whether the work is satisfactory. In such cases the difference in gross volume should not be more than 6 percent.

CHAPTER 8. COMPUTATIONS, MAPS, AND REPORT

Computations of Volume

For Strips

Gross and net volume should be computed for strips each day as the work progresses, if it is practical to do this. Then, if there are any serious errors they will show up. By computing the volume currently, inexperienced men become familiar with variations in stand per acre or per forty and develop timber sense. In sectionized country the estimate is usually shown by the forty. The data can later be summarized by section, township, logging unit, or other division.

For Sample Plots

If a statistical analysis is considered necessary, volume for each individual sample plot must be computed separately. The cruiser can then compute the approximate error of estimate, and determine whether his cruise is sufficiently intensive to give reliable results. In this manner he learns how the stand of timber per acre varies from place to place and what intensity of sampling is necessary to attain any desired degree of accuracy. On the basis of volume data for individual plots a good type map or a density map showing the stand of timber per acre can be made. The estimate can then be shown by forty, section, logging unit, or other division.

By Logging Unit and by Watershed

Volume estimates by logging unit are required by most lumbermen, and are standard practice with the Forest Service. They are valuable for such purposes as planning logging operations and letting contracts. The timber owner is interested in knowing how the timber can come out and how much timber is contained in each natural unit, particularly in mountainous country where topography controls the outlet of the timber. In country so flat as a large portion of the South, this is not important. The estimates should of course be summarized by main watershed. This is standard practice in all regions.

By Type and Age Class

Computation of volume by type and age class is usually required in Forest Service cruising. It is always necessary when estimates are summarized for a management plan.

By Diameter Class

A summary of volume by diameter class is very useful. Estimates so computed show at a glance where the value is and how much volume is in trees of the valuable sizes, that is, in large trees. It does not require very much additional time to compute and summarize the estimates by diameter class. This can be done for small units and for watersheds. A tabulation can be made showing the number of trees and the volume in each diameter class.

By Log Grade and Diameter Class

Compilation of volume data by log grade and diameter class has not, as a rule, been required, but this is the most practical form in which the volume information can be presented. It gives the best indication of value. Quality of timber is far more important than logging conditions. Large timber of high quality, if there is enough of it, can be logged profitably regardless of location or forest conditions. It is very probable that in the future cruisers will in many cases be required to present volume information in this form. The percentage of volume in each log grade can be determined from sample trees. Local volume tables can be constructed showing the percentage of tree volume represented by each log in the tree, by diameter class, for each species.

Maps

Drainage Map

A drainage map is the most common type of map required on cruising jobs. Such maps are commonly required in regions where topographic features such as lakes and water courses are important in the development of logging operations. They show the various outlets for skidding and transporting the timber, and indicate clearly the location of main streams, creeks, draws, ridges, and other features. Sometimes direction of slope is shown by means of arrows and the grade percent is marked beside each arrow. Often the grade of streams is shown.

Topographic Map

A map showing topography by means of contour lines gives a more detailed picture of the relief of the land and of drainage accessibility. The elevational difference represented by the interval between contour lines ranges in general from 20 to 100 feet, depending on the steepness of the country and the use that is to be made of the map.

Where railroad logging is contemplated, a reliable topographic map is very desirable. The logging plan can be laid out on paper, then located on the ground. The location of the timber should, of course, be shown on the map in connection with the estimate. Formerly very detailed topographic maps were made for most of the larger operating units on the Pacific Coast. Development of the tractor fof skidding, the bulldozer for grading, and the truck for transportation has made detailed topographic maps unnecessary in many cases except for locating main-line railroads.

Type Map

A forest type map is a sketch map showing the location and distribution of various land-use types, cover types, or forest conditions for units ranging to a minimum of from 40 to 2 acres, according to the detail needed and the extent of the area. For large areas the types are usually generalized on the final map, because of its small scale, to such an extent that no single type area is less than 40 acres. A type map showing by different colors the predominant species, age classes, and size classes of timber, and other forest conditions, can be superimposed on a drainage or topographic map, with the result that timber variations are correlated with topography.

Density Map

A density map shows the variation in volume of timber from place to place, by three or four gradations. Many lumbermen, loggers, and pulpwood operators are more interested in the density map than in any other.

Site-Quality and Age-Class Map

A site-quality and age-class map is often needed by the Forest Service. It is always required in the preparation of management plans. The timber is classified as to age by 10-year or, more commonly, 20-year intervals. On site-quality and age-class maps the forest cover types, also, are shown.

The Cruiser's Report

The coverage, arrangement, and length of the cruiser's report depend upon the character of the cruise and the use to be made of the information gathered. What type of report is required should be definitely understood in advance.

The simplest report is that on the usual cruise made for a client who wants to know only the quantity of saw timber on a given tract. It may include the legal description and ownership, the area of timberland cruised, and an itemized statement of the net volume of saw timber, by species. Even such a simple statement should be accompanied by a plat of the area and a statement of the sampling percentage, the log rule used, and the approximate size of the timber.

Every cruiser's report should give just the information the client requires, stated as clearly as possible, with full explanation when necessary. A brief, workmanlike report, attractively bound and accompanied by a well-drawn map, adds greatly to the value and influence of the work performed by the cruiser in the woods.

CHAPTER 9. CONSTRUCTION AND APPLICATION OF VOLUME TABLES

Field Measurements

In collecting material for the preparation of volume tables, the cruiser should bear in mind that the trees he selects for measurement should represent the average run of trees as they occur over large areas and under different forest conditions. The reliability of a volume table as a means of estimating the quantity of timber on a given tract depends primarily on how well it represents the average form of all the trees on the tract. Some of the reasons why variations must be taken into account are these: Old-growth timber, particularly pine, usually has better form (less taper) than second growth; dense stands, as a rule, produce trees of better form than do stands that are poorly stocked; suppressed trees have less taper than trees that are decidedly open-grown. Sample trees to be measured for volume-table construction should be chosen not all in one place but well distributed throughout the locality in which the volume table will be applied, unless the cruiser is quite certain that the timber in that place is representative of the timber in the locality as a whole.

For measuring volume of felled trees, the estimator needs the following equipment: A notebook, a steel diameter tape or a pair of calipers, a 100-foot tape for measuring length, and a Swedish bark punch for determining bark thickness.

The main points to keep in mind regarding field measurements are these:

1. Diameter should be measured carefully to the nearest 1/10 inch, with the diameter tape or, preferably, with calipers. In using the former, care should be taken to avoid kinks in it. Calipers should be kept in proper adjustment.

2. One measurement at each point is sufficient, if there are no abnormalities at the point of measurement and if in all cases the diameter tape or the caliper arms are placed at right angles to the axis of the tree.

3. Breast-height diameter should be taken 4½ feet from the ground, except in the case of butt-swelled trees such as cypress, tupelo gum, and swamp black gum. In such species it is usually taken 18 to 24 inches above the pronounced swell. On flat areas, the point of measurement of breast-height diameter is established 4½ feet above the average ground level; on slopes, it is established 4½ feet above the ground on the uphill side of the tree. If roots protrude above the ground, d.b.h. is taken 4½ feet above the root collar. On leaning trees, it is taken at a point 4½ feet along the bole. If the bole is distorted at breast height by knots, abnormal swellings, or depressions two measurements are taken, one above and another below the distortion, and the two readings are averaged; or, preferably, the tree is omitted.

4. D.b.h. should be taken both outside and inside the bark. Bark thickness can be measured with a Swedish bark punch, or, if this instrument is not available, an ax can be used to remove the bark from each side of the trunk at points of measurement. If the actual cut coincides with the point of measurement a small graduated scale may be used to measure the bark. The cruiser must make sure that the bark has not been smoothed off at the point of measurement by the cutters. Bark thickness is measured at the highest and lowest ridges of the bark at the cross-cut section, and the two readings are averaged; it is not measured at depressions, because the diameter tape or the calipers touch the ridges only. If a bark measurer is used the single bark thickness is doubled. Bark thickness in all diameter measurements should be taken to the nearest 1/500 inch.

5. The diameter measurements at each log point should be taken the same as d.b.h., outside and inside bark, to the nearest 1/10 inch in small timber and to the nearest inch in large timber.

6. Trees with flat boles should not be included unless two caliper measurements, at right angles, can be taken at each point of diameter measurement. The two measurements should be averaged.

7. Merchantable bole should generally be measured in 16-foot or 8-foot log lengths, with whatever trimming allowance is standard for the region. For coniferous species in most regions, volumes are usually tabulated in 16-foot log lengths; for hardwoods they are sometimes shown in log lengths as short as 8 feet. On the Pacific Coast, cruisers often use log lengths of 32 to 40 feet. The most common standard is 16.3 feet. Tops of first, second, third, and other successive standard logs are measured at distances above the stump of 32.6, 48.9, and 65.2 feet, etc.

Board-Foot Volume Tables

Methods of constructing board-foot volume tables include the frustum form-factor method, form-class method, alinement-chart methods, multiple-regression-equation method, logarithmic-equation method, and others. Many articles have been written on these methods, so that it is unnecessary to discuss them here. They are too complicated for the general run of cruisers. The writers will present here only what they consider simple but reliable methods of constructing board-foot volume tables.

Form-Class Taper Method

One method of constructing board-foot volume tables that is very simple and gives results close enough for all practical purposes is the form-class taper method. "Form class", as used here, does not mean what foresters ordinarily term "form class" or "form quotient." The latter is the ratio of the diameter at the point halfway between breast height and the tip to d.b.h. The form class referred to here is the ratio of the top diameter inside bark of the first 16-foot log to d.b.h. outside bark. If a tree is 24 inches in diameter outside bark at breast height and 19.2 inches in diameter inside bark at the top of the first 16-foot log, its form class is 19.2 divided by 24, or 0.80. Volume-table construction by the form-class taper method requires knowledge both of this ratio and of taper above the top of the first log. Experience with many species has shown that a satisfactory table can be made by this method from data on 100 properly selected and carefully measured trees, if the spread in diameter is not too great. Two men can easily measure 100 trees in a day in such species as ponderosa pine, the white pines, or the southern pines. After the field measurements are taken the volume table can be completed in one day. If a man is an expert in estimating form class and taper and has a recorder, he can take enough trees in two or three hours to make a good local volume table, and if necessary the computing can be done and the table completed the same day. Detailed checks in different parts of the country, involving many species and measurement of several million feet of cut trees, have proved the reliability of the tables.

If the trees range from 16 to 40 inches in d.b.h., it is recommended that they be classified in four diameter groups: 16 to 20 inches, 22 to 26 inches, 28 to 32 inches, and 34 to 38 inches. If 20 to 30 trees are measured for each of these diameter groups a very good table can be constructed, provided the timber measured is a good sample of that on the tract as a whole. Average form class and taper should be determined for each diameter group, and the volume of the average tree of each group computed by applying these values to the middle diameter class in each group; for example, the average form class and taper determined for the 16- to 20-inch group should be applied to the 18-inch tree. The even number that is the middle point of the diameter range is not, of course, the exact average diameter of the group as determined from the measurements; it is used instead of the true average for convenience in making calculations.

In cases in which diameters of trees are measured instead of being estimated, the trees can be scaled and the table made without reference to form class. The only value in determining form class and taper in such cases is that men thus learn to recognize the form and taper of timber and acquire knowledge of tree volume.

If the form class and taper are estimated, it is not necessary to make any diameter measurements except enough to serve as a check on the estimator's judgment. If the timber ranges only from 10 to 24 inches in d.b.h., diameters should be estimated within 1 percent or less of actual measurement. If an error of even 5 percent were made in estimating certain diameters, however, this would have no material effect on the accuracy of the volume table unless the errors were all in one direction. Small errors in estimating diameters usually are compensating and have no effect whatever on the form class and taper averages. If no operations are in progress near by, estimates of form class can be checked by using tree climbers, a diameter tape, and a bark punch.

When a table is to be made without measuring any trees, a sufficient number of trees should be taken in each diameter class to make a strong curve of volume over diameter for each log. These trees should be selected in some mechanical or random fashion, so as to get an unbiased representation of the stand. The trees should be recorded by 2-inch diameter class. The final calculations for each 2-inch diameter class should be made on a separate sheet. Average form class and taper should be determined for each diameter class and applied to the theoretical average diameter.

It is very important that the forms used for recording the tree data present the information clearly. The form for taking volume data shown in figures 1 and 2, which was developed in the South in connection with the Nation-wide Forest Survey, has proved very satisfactory. Condition of stand and topography are designated by code number; in the record for cut trees (figure 1), "1" in the second column means old-growth timber, and "2" in column three means rolling uplands. If desired, "Topography" can be crossed out and "Site index" written in. In the fourth column, "1" in this case means longleaf pine. In the "d.b.h." column the top figure, 12.9, is d.b.h. inside bark; the second figure, 14.0, is d.b.h. outside bark; and the third figure, 1.1, is double bark thickness. The "1" column under "Measurement of indicated log" shows that the first 16-foot log has a top diameter outside bark of 12.8 inches, a double bark thickness of 1.0 inch, and a top diameter inside bark of 11.8 inches. In the record for standing trees (figure 2), the same code numbers are used. Here, the first tree is 24 inches in d.b.h. outside bark, its estimated form class is 0.80, and the estimated top diameter inside bark of its first 16-foot log is 0.80 x 24 inches, or 19.2 inches. The estimated taper in the second 16-foot log is 1.5 inches, so the estimated top diameter inside bark of the second 16-foot log is 19.2 - 1.5 inches, or 17.7 inches. The top diameter of each log inside bark is shown for the first tree, to illustrate the procedure followed if the volume of each sample tree is computed. All logs are 16 feet long unless otherwise designated. It will be noted that the length of the last log in tree number 4 is recorded as 8 feet, and that of the last log in tree number 6 is recorded as 10 feet.

If data for 10 trees are entered on the sheet, adding all the form-class values and pointing off one figure to the left gives the average form class, and adding the tapers of all the logs in each column and pointing off two figures to the left gives the average taper.

The form provides for a record of the pulpwood in the tops, also for a record of the hardwood log grades.

State ____________ Estimator ____________ Date ________
Unit ____________
County ____________ Recorder ____________ Plot # 1

Tree number	Condition	Topography	Species code number	DBH	Measurement of indicated log							Merchantable length	Total tree volume, in feet BM	Pulp top diameter, length, and taper	Hardwood log grades				
						1	2	3	4	5	6								
1	1	2	1	12.9	DIB	11.8	9.8					32	135						
				14.0		12.8	10.8												
				1.1		1.0	1.0												
2	1	2	1	20.8	DIB	17.8	16.4	14.9	12.8	8.7		64	666						
				22.2		19.0	17.6	16.0	14.0	10.0									
				1.4		1.2	1.2	1.1	1.2	1.3									
3	1	2	1	28.2	DIB	24.0	22.0	19.8	17.3	14.2		64	1,462						
				30.0		25.2	23.2	21.0	18.5	15.5									
				1.8		1.2	1.2	1.2	1.2	1.3									
					DIB														
					DIB														
					DIB														
					DIB														
					DIB														
					DIB														
					DIB														

Figure 1.--Record of volume-table measurements of cut trees.

State ____________ Estimator ____________ Date ____________
Unit ____________
County ____________ Recorder ____________ Plot # 2

Tree number	Condition	Topography	Species code number	DBH	Measurement of indicated log							Merchantable length	Total tree volume, in feet BM	Pulp top diameter, length, and taper	Hardwood log grades	
						1	2	3	4	5	6					
1	1	2	1		DIB	19.2	17.7	15.9	13.4	10.4						
				24		.80	1.5	1.8	2.5	3.0						
2	1	2	1		DIB											
				20		.84	1.4	1.7	2.2							
3	1	2	1		DIB											
				24		.82	1.6	2.0	2.5	3.0						
4	1	2	1		DIB											
				16		.81	1.4	1.8	1.2 8.							
5	1	2	1		DIB											
				16		.83	1.3	1.7	2.0							
6	1	2	1		DIB											
				16		.80	1.5	1.8	2.0 10.							
7	1	2	1		DIB											
				18		.84	1.2	1.6	2.2							
8	1	2	1		DIB											
				18		.82	1.5	2.0								
9	1	2	1		DIB											
				20		.81	1.6	1.9	2.3							
10	1	2	1		DIB											
				28		.80	1.8	2.2	3.0							
Average						.817	1.48	1.85	2.21	3.0						

Figure 2.--Record of volume-table data for standing trees.

This method of table construction is illustrated by data for 95 ponderosa pine trees that were measured in Klamath County, Oregon. This timber was of high form class for ponderosa pine, having a taper considerably less than the average for this species. The measurements were taken with calipers. Table 3 shows how the volume table was built up. Average top diameter inside bark of the first log was calculated for each d.b.h. group by multiplying the middle d.b.h. by the average form class. Average top diameter of the second log was arrived at by subtracting the taper of the second log from the diameter of the first. Volumes were determined by reference to the Scribner log rule (table 46, appendix). The next step was to curve the volume, using either ordinary cross-section paper or semilogarithmic paper. Figure 3 shows how this is done. The four points representing the average scale of the butt log in each diameter group, respectively, are connected with a smooth curve, 2/ and from this curve the volume of the butt log is read for each diameter class. Curves are made similarly for the volume of two logs, three logs, etc. Table 4 is the volume table read from the curves shown in figure 3.

2/ Methods of drawing freehand curves are described in the appendix.

Table 3.--Volume-table data for 95 ponderosa pines on an area in Klamath County, Oreg.

Breast-height-diameter group (inches)	Breast-height diameter used	Average form class	Average taper (inches), top diameter inside bark (inches), and cumulative volume (board feet)[1] for successive 16-foot logs						
			Log 1	Log 2	Log 3	Log 4	Log 5	Log 6	Log 7
	Inches	Percent							
16 - 20	18	79.0		1.1	1.4	1.7	2.1		
			14.2	13.1	11.7	10.0	7.9		
			127	232	313	368	398		
22 -26	24	82.0		1.3	1.6	2.1	2.7	3.5	
			19.7	18.4	16.8	14.7	12.0	8.5	
			263	490	675	812	898	934	
28 -32	30	82.0		1.1	1.6	2.3	3.4	4.7	
			24.6	23.5	21.9	19.6	16.2	11.5	
			425	810	1,141	1,401	1,572	1,649	
34 -38	36	82.5		1.0	1.5	2.2	3.0	3.8	4.7
			29.7	28.7	27.2	25.0	22.0	18.2	13.5
			633	1,222	1,748	2,188	2,522	2,743	2,856

[1] Scribner.

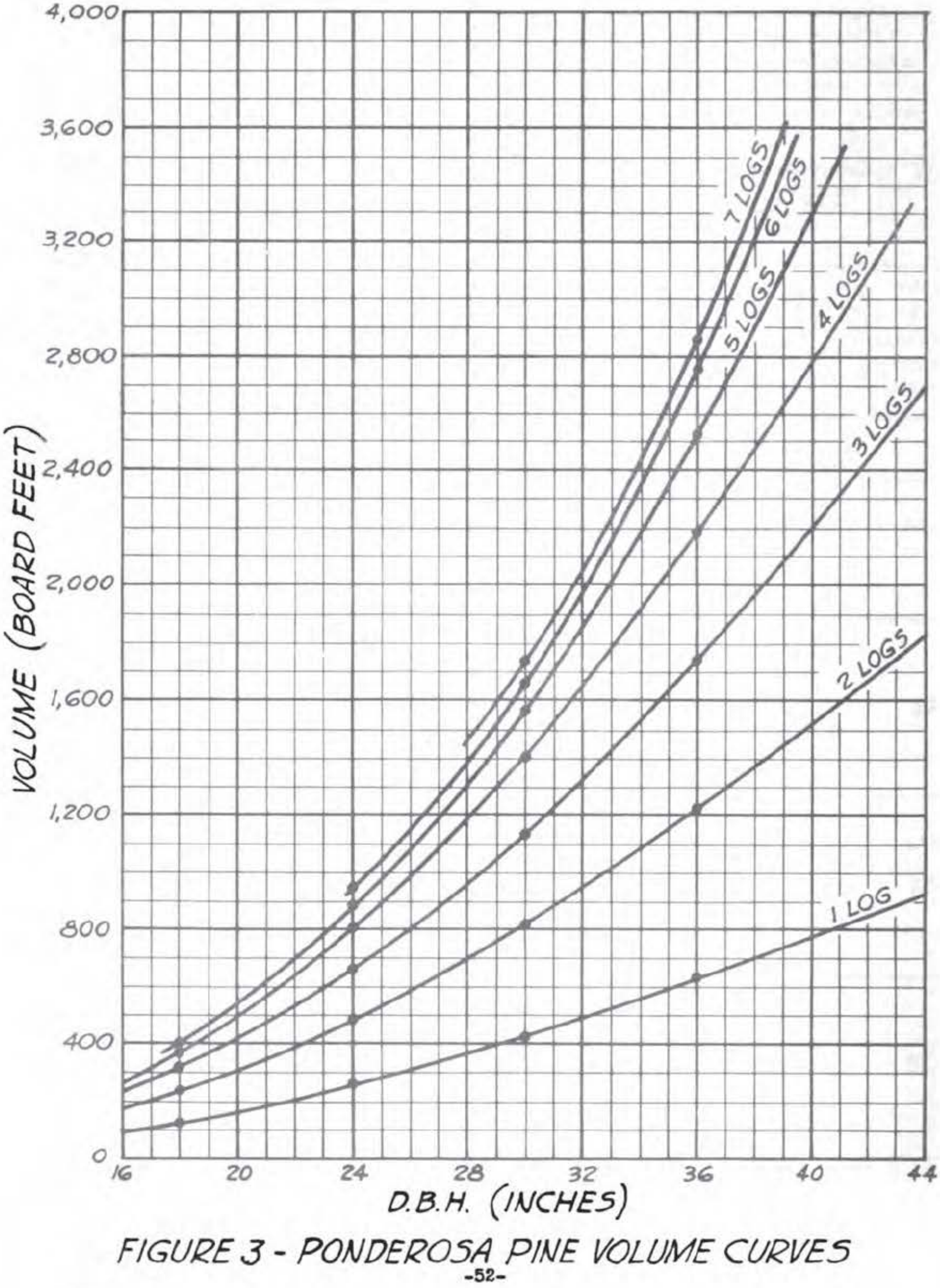

FIGURE 3 - PONDEROSA PINE VOLUME CURVES

Table 4.--Volume[1] table for ponderosa pine in Klamath County, Oreg.

Breast-height diameter (inches)	Volume, by merchantable height in 16-foot logs						
	1 log	2 logs	3 logs	4 logs	5 logs	6 logs	7 logs
	Board feet	Board feet	Board feet	Board feet	Board feet	Board feet	Board feet
16	90	160	220	260			
18	125	230	310	370	400		
20	170	310	410	500	540		
22	215	395	530	640	710	740	
24	260	485	660	800	880	930	
26	310	595	800	980	1,090	1,140	
28	365	700	960	1,190	1,310	1,380	
30	420	810	1,130	1,400	1,570	1,660	1,730
32	480	940	1,320	1,650	1,860	1,990	2,060
34	550	1,075	1,525	1,900	2,180	2,350	2,450
36	625	1,215	1,740	2,180	2,520	2,760	2,870
38	700	1,368	1,970	2,460	2,870	3,200	3,350
40	790	1,520	2,210	2,760	3,250	3,660	3,860
42	870	1,690	2,460	3,070	3,640	4,110	4,300

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[1] Scribner.

A table showing volume by merchantable height in log lengths is particularly useful in cases in which the volume of each grade of logs is required.

Table 5 shows the volume-table scale in comparison with the actual scale of the 95 trees. The top utilization diameter of 10.2 inches corresponds to an 18-inch d.b.h., that of 11.4 inches to a 24-inch d.b.h., etc.

This method of volume-table construction is further illustrated by data for 127 old-growth longleaf pines on an area in Louisiana. The taper in this timber is slightly greater than the average for old-growth longleaf pine in the South. The details of computing average form class and taper for the 38 trees in the 12- to 16-inch diameter group are shown in table 6.

Table 5.-- Check of table 4 against data in table 3

Breast-height diameter group (inches)	Trees	Total volume as shown by-- Actual scale	 Volume-table scale	Average top utilization diameter
	Number	Board feet	Board feet	Inches
16 -20	15	5,464	5,510	10.2
22 -26	28	23,510	23,810	11.4
26 -32	24	38,691	38,990	15.5
34+	28	80,857	80,000	16.2
Total	95	148,522	148,310	
Difference in total scale			- 212 Percent - 0.014	

Table 6.--Computation of average form class and taper for 38 measured cut old-growth longleaf pines of the 12- to 16-inch diameter group on an area in Louisiana

Tree (number)	Breast-height diameter	Form class	Top diameter inside bark of (16-foot) log number -- 1	2	3	4
	Inches	Percent	Inches	Inches	Inches	Inches
1	12.4	83.1	10.3	8.7	7.3	
2	12.7	86.6	11.0	9.8	8.5	
3	11.6	86.2	10.0	9.0	7.4	
4	12.7	81.9	10.4	9.1	7.8	
5	11.4	85.1	9.7	8.7	7.3	
6	11.6	86.2	10.0	8.9	7.4	
7	14.2	86.6	12.3	10.4	9.0	
8	14.6	89.0	13.0	12.2	10.2	8.3
9	14.9	84.6	12.6	10.6	8.9	
10	14.0	82.9	11.6	10.6	8.6	6.8
11	13.0	83.1	10.8	9.8	8.4	
12	14.1	85.8	12.1	10.6	9.1	
13	13.0	86.2	11.2	10.2	9.0	7.0
14	13.4	83.6	11.2	9.9	8.5	
15	14.0	82.1	11.5	10.5	8.9	7.4
16	16.0	82.5	13.2	12.2	10.1	
17	15.9	88.1	14.0	12.4	10.2	8.4
18	15.7	86.0	13.5	11.9	10.6	8.4
19	15.3	87.6	13.4	11.5	10.3	8.5
20	16.0	81.9	13.1	11.2	8.7	
21	16.1	87.0	14.0	12.4	11.1	
22	15.6	80.1	12.5	11.3	9.7	7.4
23	16.0	91.2	14.6	13.0	11.1	8.6
24	16.9	85.8	14.5	14.1	11.1	
25	16.8	86.9	14.6	12.7	10.7	
26	15.0	86.7	13.0	11.5	10.0	
27	16.6	88.6	14.7	13.1	10.5	
28	16.4	84.1	13.8	12.0	10.5	
29	16.0	84.4	13.5	12.2	10.4	8.7
30	16.2	86.4	14.0	12.5	10.7	8.4
31	16.4	82.3	13.5	11.6	10.0	8.0
32	16.6	83.1	13.8	12.2	10.1	
33	16.5	85.5	14.1	12.7	10.9	8.7
34	16.0	81.2	13.0	11.6	10.3	8.2
35	15.4	87.7	13.5	11.8	10.4	8.3
36	14.2	86.2	12.2	11.0	9.2	
37	16.0	79.4	12.7	11.4	9.1	
38	16.6	84.3	14.0	12.4	11.1	9.3
Total		3,230.0	480.9	427.7	363.1	130.4
Average		85.0				
Taper				1.40	1.70	2.00

By dividing the sum of the form classes of all the trees by 38, it was determined that the form class of the 12- to 16-inch group averaged 85 percent. Multiplying 14 inches, the diameter taken as average for that group, by 0.85 gave 11.90 inches as the average top diameter of the first 16-foot log. Subtracting the sum of the estimated top diameters of the second logs from that of the first logs and dividing by 38 gave 1.40 inches as the average taper in the second log. Subtracting this value from 11.90 inches gave 10.50 inches as the average top diameter of the second log. The same calculations were made for additional logs in the 12- to 16-inch trees and for trees of the 18- to 22-inch and 24- to 26-inch diameter groups, and average volumes were computed. The results are shown in table 7. The average log volumes were then plotted on cross-section paper, the points connected with a curve for the first log, first and second log, etc. (figure 4), and volumes for all diameter classes were read from the curves (table 8). The volume-table scale is compared with the actual scale in table 9.

Table 7.--Volume-table data for 127 old-growth longleaf pines on an area in Louisiana

Breast-height-diameter group (inches)	Breast-height-diameter used	Average form class	Average taper (inches), top diameter inside bark (inches), and cumulative volume (board feet) 1/ for successive 16-foot logs					Average top utilization diameter
			Log 1	Log 2	Log 3	Log 4	Log 5	
	Inches	Percent						Inches
12 - 16	14	85.0		1.40	1.70	2.00		8.0
			11.90	10.50	8.80	6.80		
			84	146	186	205		
18 - 22	20	83.0		1.70	2.10	2.40	3.00	10.3
			16.60	14.90	12.80	10.40	7.40	
			180	322	422	483	507	
24 - 28	26	83.5		2.00	2.33	2.50	3.00	13.2
			21.71	19.71	17.38	14.88	11.88	
			325	588	788	930	1,014	

1/ Scribner.

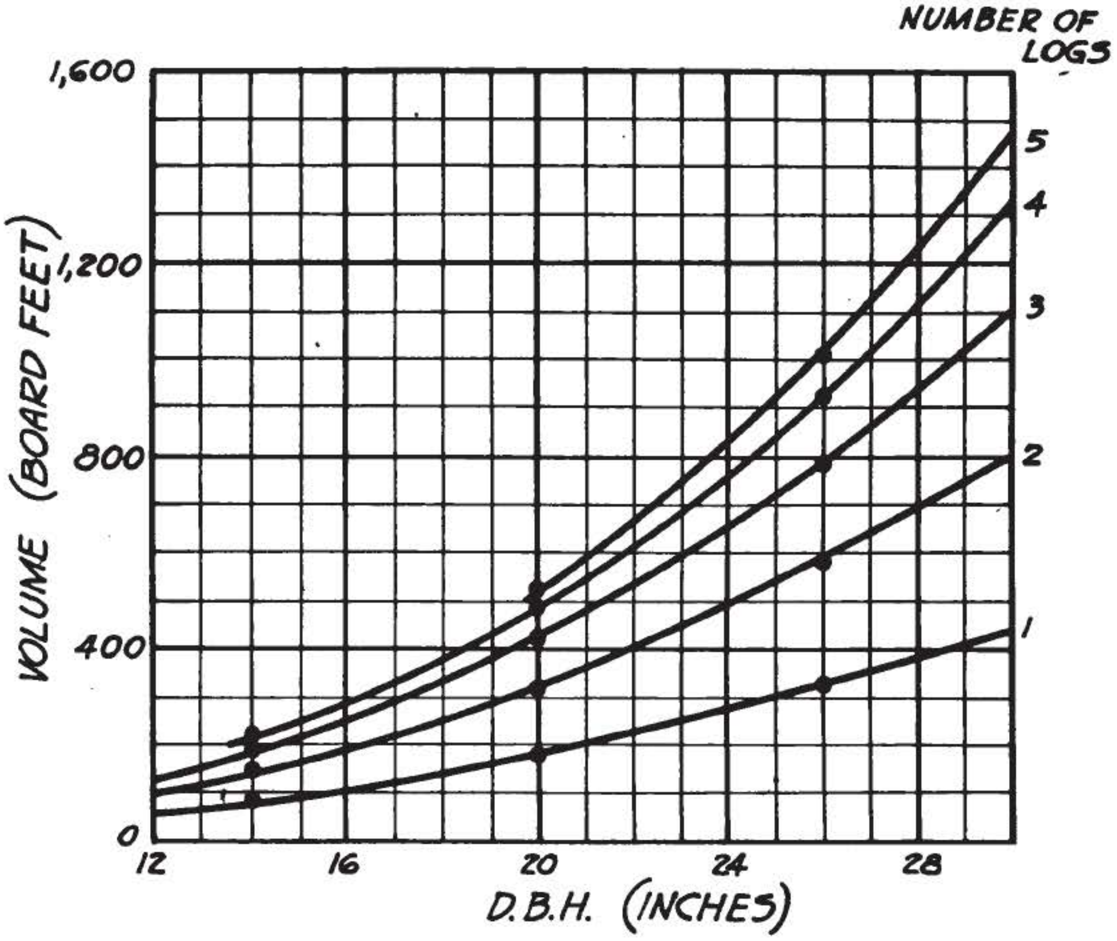

FIGURE 4 - LONGLEAF PINE VOLUME CURVES

Table 8.--Volume[1] table for old-growth longleaf pine on an area in Louisiana

Breast-height diameter (inches)	Volume, by merchantable height in 16-foot logs				
	1 log	2 logs	3 logs	4 logs	5 logs
	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.
12	60	105	130	143	
14	85	150	190	210	
16	110	195	257	290	
18	140	250	335	385	400
20	182	320	425	490	520
22	225	400	535	615	660
24	275	490	650	755	820
26	325	585	785	925	1,010
28	380	690	937	1,110	1,230
30	440	800	1,110	1,330	1,470

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[1] Scribner.

Table 9.--Check of table 8 against data in table 7

Breast-height-diameter group (inches)	Trees	Total volume as shown by --	
		Actual scale	Volume-table scale
	Number	Bd. ft.	Bd. ft.
12 - 16	38	9,257	8,938
18 - 22	65	29,780	30,150
24 - 30	24	23,524	23,518
Total	127	62,561	62,606
Difference in total scale			+ 45

A somewhat better volume table would have been obtained if average form class and taper had been calculated and applied for each 2-inch diameter class. In timber ranging only from 10 to 18 inches in diameter, a sufficient number of trees should be taken to do this. Ordinarily, from 15 to 25 trees are required in each diameter class. The table could be further improved for individual trees by determining form class and taper for each merchantable-height class, but this would require measuring more trees and would take much more time. If the diameters range from 16 to 50 inches, at least four or five diameter groups should be used.

This is a very rapid method of making volume tables. After thoroughly training himself, any intelligent forester with a natural inclination for this line of work can make volume tables by this method that will check within 1 or 2 percent of actual scale, for timber running 3 to 5 logs per tree, without measuring any trees. Experience has proved this in many cases. This self-training, however, involves careful study, close observation of timber form and taper, and many checks by measuring cut trees on logging operations or measuring standing trees by the use of diameter tape, tree climbers, and a bark punch.

When 300 or more sample trees are taken for each species and forest condition, the volume of each sample tree is computed and the volume table is based on diameter only. The number of sample trees necessary depends on the spread in diameter.

Although volume tables constructed by the form-class taper method give good results for the general run of timber, this method does not take fully into account the association of taper with the log height of trees within a given d.b.h. class. The taper of the merchantable bole of a 4-log tree, for instance, is usually considerably less than the taper of a tree having the same d.b.h. but a merchantable height of only 2 logs. For this reason, volumes of individual trees as read from tables so constructed may differ considerably from the actual volumes.

Chapter 10 contains further discussion of form class and taper, and outlines the best procedure for developing ability to estimate these values with reasonable accuracy.

Form-Diameter Method

For those who need volume tables giving closer estimates by individual diameter and height classes than the tables obtained by the form-class taper method, another simple method is suggested. This consists in determining the trend of the relation between the general form of the merchantable boles of trees and their board-foot volume, separately for each d.b.h. and height class. The measure of this general form, or the degree of fulness of the merchantable bole, is the single value called form diameter. Form diameter is the product of d.b.h. and form class (the top diameter inside bark of the first 16-foot log) divided by a factor denoting the rate of taper of the merchantable stem above the butt log. This factor, known as the taper factor, is fully discussed in the appendix, and tables of taper factors are given there.

As an example let us take a tree for which the d.b.h. is 20 inches, the top diameter of the butt log is 15.6 inches, the form class consequently is 15.6/20.0, or 0.78, the taper between the first and second 16-foot logs is 1.5 inches, and the taper between the second and third logs is 2.0 inches. Now, if this tree contains exactly three merchantable logs and the taper factor of the upper logs is 0.814, the tree's form diameter is $\frac{20 \text{ inches} \times 0.78}{0.814}$, or 19.2 inches.

The taper factors of individual trees vary considerably. They are high if the rate of taper above the butt log is rapid and low if it is slow. Obviously, any change in taper factor produces a corresponding change in form diameter. Had the taper factor in the example just given been 0.830, instead of 0.814, the form diameter of the tree would have been 18.8 inches instead of 19.2 inches. Obviously, also, the higher the form class the higher the form diameter. For the general run of timber, the factor of taper above the butt log is approximately 0.82 and the form diameter amounts to about 122 percent of the top diameter of the first log.

The form-diameter method of table construction is applicable only to trees not exceeding 6 standard logs, or 97.8 feet, in merchantable length.

Curves of volume over form diameter, one curve for each log height, have been prepared on the basis of a large number of stem measurements in timber of different sizes and species. These basic curves are represented in table 10. According to table 10, for example, a 3-log tree having a form diameter of 19.2 inches contains 370 board feet, Scribner rule. An almost identical volume figure is obtained by scaling the individual logs. The top diameters inside bark of the three merchantable logs are 15.6, 14.1, and 12.1 inches. The volumes of such logs (see table 46, appendix), respectively, are 157, 125, and 87 board feet Scribner.

The first step in preparing board-foot volume tables by the form-diameter method is to choose sample trees. After observing the entire range of tree sizes in a given locality, the cruiser should concentrate on certain size groups, such as the trees 12, 16, 20, 24, 28, and 32 inches in d.b.h. and 1, 2, 3, 4, and 5 (16-foot) logs in height, and measure about 25 trees in each of these diameter-height groups.

Table 10.—Relation between board-foot volume and form diameter [1]

2-LOG TREES

Form diameter (inches)	Volume, by additional tenths of an inch of form diameter									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.
9	38	40	41	42	43	44	46	48	49	50
10	51	52	53	54	56	58	60	62	63	65
11	67	69	71	73	75	77	79	81	82	84
12	86	88	90	91	93	95	97	99	101	103
13	105	107	110	112	115	117	119	121	123	125
14	127	129	131	133	136	139	141	144	147	150
15	153	155	157	160	163	166	169	171	173	176
16	179	181	183	186	189	192	195	198	200	202
17	205	207	210	212	214	217	220	223	226	229
18	232	235	239	242	245	249	252	255	258	261
19	265	268	271	274	278	281	284	288	291	294
20	298	301	304	307	310	313	316	320	324	328
21	331	334	338	342	346	350	353	357	361	365
22	369	373	377	381	385	389	393	396	400	404
23	409	413	417	421	426	430	434	438	442	446
24	450	454	459	463	468	472	476	480	484	488
25	492	496	500	505	509	513	518	523	528	533
26	538	543	548	553	558	563	568	572	577	582
27	587	592	596	600	605	609	614	619	623	628
28	633	638	642	647	652	657	662	667	672	677
29	682	688	694	699	704	710	715	721	726	731
30	736	741	746	751	756	761	766	771	776	781
31	787	792	798	803	808	813	819	825	831	836
32	842	848	853	859	865	870	875	881	887	893
33	899	904	909	914	920	926	931	937	942	948
34	954	960	966	972	978	984	990	996	1,002	1,008
35	1,014	1,020	1,026	1,032	1,038	1,045	1,051	1,057	1,064	1,070
36	1,077	1,084	1,090	1,097	1,102	1,108	1,113	1,119	1,125	1,131
37	1,137	1,143	1,149	1,155	1,161	1,167	1,173	1,179	1,185	1,191
38	1,197	1,203	1,209	1,215	1,221	1,227	1,233	1,239	1,245	1,251
39	1,257	1,263	1,269	1,275	1,281	1,287	1,293	1,299	1,305	1,311
40	1,318	1,325	1,332	1,338	1,344	1,351	1,358	1,364	1,370	1,377

[1] 16.3-foot logs.

Table 10—Relation between board-foot volume and form diameter—continued

3-LOG TREES[1]

Form diameter (inches)	Volume, by additional tenths of an inch of form diameter									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.
9										
10	64	66	69	71	73	75	78	81	83	86
11	89	91	93	95	98	100	102	104	107	110
12	112	114	117	120	123	126	129	132	135	138
13	141	144	147	151	154	157	160	163	166	169
14	172	175	178	181	185	188	191	195	199	202
15	206	209	212	216	220	223	226	230	233	236
16	240	244	248	252	255	258	262	266	270	274
17	278	282	286	290	294	298	302	306	309	312
18	316	320	324	329	334	339	344	348	352	357
19	362	366	370	374	378	382	387	392	397	402
20	407	411	416	421	426	430	435	439	443	448
21	452	457	461	466	471	476	481	486	490	495
22	500	505	510	515	520	525	530	535	540	545
23	550	555	560	565	570	575	581	586	592	598
24	603	608	613	618	623	628	633	639	645	651
25	657	663	670	677	684	691	698	704	710	717
26	724	730	737	743	749	755	761	768	774	780
27	786	792	798	804	810	816	824	830	836	841
28	848	854	860	867	874	881	888	896	903	910
29	917	924	930	936	942	948	954	960	967	973
30	980	987	994	1,001	1,008	1,015	1,022	1,030	1,037	1,045
31	1,052	1,059	1,066	1,073	1,080	1,088	1,096	1,103	1,111	1,119
32	1,127	1,134	1,141	1,148	1,156	1,163	1,170	1,178	1,185	1,193
33	1,200	1,207	1,214	1,222	1,230	1,238	1,245	1,252	1,259	1,266
34	1,273	1,281	1,289	1,296	1,304	1,311	1,319	1,327	1,335	1,343
35	1,350	1,358	1,366	1,373	1,381	1,389	1,397	1,405	1,412	1,419
36	1,426	1,434	1,441	1,448	1,456	1,464	1,471	1,478	1,485	1,492
37	1,500	1,507	1,515	1,523	1,531	1,538	1,546	1,554	1,561	1,570
38	1,579	1,586	1,594	1,601	1,609	1,616	1,624	1,631	1,639	1,647
39	1,655	1,663	1,671	1,679	1,687	1,695	1,703	1,711	1,719	1,727
40	1,735	1,743	1,752	1,760	1,769	1,777	1,786	1,794	1,803	1,811

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[1] 16.3-foot logs.

Table 10 .--Relation between board-foot volume and form diameter--continued

4-LOG TREES 1/

Form diameter (inches)	Volume, by additional tenths of an inch of form diameter									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.
9										
10	82	84	87	90	93	96	99	102	104	106
11	109	111	114	117	120	123	126	129	132	135
12	138	141	144	147	150	153	156	159	162	166
13	169	172	175	179	183	187	190	193	197	200
14	204	207	210	213	216	220	224	228	232	236
15	240	244	248	252	256	260	264	269	273	277
16	281	285	290	295	299	303	306	310	315	320
17	324	329	333	338	342	346	350	354	359	363
18	368	372	377	381	386	391	396	401	406	411
19	417	422	428	433	438	444	450	456	462	468
20	470	476	482	488	494	500	506	511	516	522
21	528	534	540	546	552	558	564	570	576	582
22	588	592	599	605	611	618	625	632	639	646
23	653	660	667	674	681	687	694	700	706	713
24	720	727	734	741	748	755	762	769	776	783
25	790	797	804	811	818	825	832	849	847	854
26	861	869	876	883	890	898	906	914	921	928
27	936	943	950	957	965	972	980	988	997	1,005
28	1,012	1,019	1,027	1,036	1,044	1,052	1,060	1,068	1,076	1,084
29	1,092	1,100	1,109	1,118	1,127	1,136	1,145	1,154	1,162	1,170
30	1,179	1,187	1,196	1,204	1,212	1,220	1,229	1,238	1,247	1,255
31	1,263	1,271	1,279	1,288	1,297	1,305	1,313	1,321	1,330	1,339
32	1,348	1,357	1,366	1,375	1,384	1,392	1,400	1,409	1,418	1,427
33	1,436	1,446	1,455	1,464	1,473	1,482	1,491	1,500	1,509	1,518
34	1,527	1,536	1,545	1,553	1,562	1,571	1,580	1,589	1,598	1,606
35	1,615	1,624	1,633	1,642	1,651	1,660	1,669	1,678	1,687	1,697
36	1,707	1,717	1,727	1,737	1,747	1,757	1,767	1,777	1,786	1,795
37	1,804	1,813	1,822	1,831	1,840	1,849	1,858	1,867	1,876	1,885
38	1,894	1,903	1,912	1,922	1,932	1,942	1,952	1,962	1,972	1,982
39	1,992	2,002	2,012	2,022	2,032	2,042	2,052	2,062	2,072	2,082
40	2,092	2,102	2,112	2,122	2,132	2,142	2,152	2,162	2,172	2,182

1/ 16.3-foot logs.

Table 10.--Relation between board-foot volume and form diameter--continued

5-LOG TREES[1/]

Form diameter (inches)	Volume, by additional tenths of an inch of form diameter									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.
16	310	316	321	326	332	337	342	347	352	357
17	362	367	373	378	383	388	393	399	405	410
18	415	421	427	433	439	445	451	457	463	469
19	475	481	488	494	501	507	513	520	526	533
20	540	546	553	559	566	572	579	585	592	598
21	605	612	619	626	633	640	647	654	662	670
22	678	685	693	701	708	716	723	731	739	747
23	755	762	770	777	785	792	800	807	815	822
24	831	838	846	854	862	870	879	887	896	904
25	912	921	930	938	947	956	965	973	982	991
26	1,000	1,009	1,018	1,026	1,035	1,044	1,053	1,062	1,070	1,079
27	1,088	1,097	1,106	1,115	1,124	1,133	1,142	1,151	1,160	1,170
28	1,180	1,189	1,199	1,208	1,218	1,227	1,237	1,246	1,256	1,265
29	1,275	1,285	1,295	1,305	1,315	1,325	1,335	1,345	1,355	1,365
30	1,375	1,385	1,395	1,405	1,415	1,425	1,435	1,445	1,455	1,465
31	1,475	1,485	1,495	1,505	1,515	1,525	1,535	1,545	1,555	1,565
32	1,575	1,585	1,595	1,605	1,615	1,625	1,635	1,646	1,657	1,668
33	1,678	1,688	1,699	1,709	1,720	1,730	1,741	1,751	1,762	1,773
34	1,783	1,794	1,805	1,816	1,827	1,838	1,849	1,860	1,872	1,884
35	1,895	1,905	1,916	1,926	1,937	1,947	1,958	1,968	1,979	1,989
36	2,000	2,012	2,024	2,036	2,048	2,060	2,072	2,084	2,096	2,108
37	2,120	2,132	2,145	2,157	2,170	2,182	2,195	2,207	2,220	2,232
38	2,245	2,257	2,269	2,281	2,293	2,305	2,317	2,329	2,341	2,353
39	2,365	2,378	2,392	2,405	2,419	2,432	2,446	2,459	2,473	2,486
40	2,500	2,514	2,528	2,542	2,556	2,570	2,584	2,598	2,612	2,626

[1/] 16.3-foot logs.

Table 10.--Relation between board-foot volume and form diameter--continued

6-LOG TREES 1/

Form diameter (inches)	Volume, by additional tenths of an inch of form diameter									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.
16	340	345	351	357	363	369	375	381	387	393
17	399	405	411	417	423	429	435	441	447	453
18	460	466	472	478	485	492	499	506	513	520
19	527	534	541	548	555	561	568	576	584	592
20	600	607	614	622	630	638	646	654	662	670
21	678	686	694	702	711	720	729	738	747	756
22	765	774	783	792	801	810	819	828	837	847
23	857	866	875	885	895	905	915	925	935	945
24	955	965	975	985	995	1,005	1,015	1,025	1,035	1,045
25	1,056	1,066	1,076	1,086	1,096	1,106	1,117	1,127	1,138	1,149
26	1,160	1,171	1,182	1,193	1,204	1,215	1,226	1,237	1,248	1,259
27	1,270	1,281	1,293	1,304	1,316	1,317	1,329	1,340	1,352	1,363
28	1,385	1,396	1,408	1,419	1,431	1,442	1,454	1,465	1,477	1,488
29	1,500	1,511	1,523	1,534	1,546	1,557	1,569	1,580	1,592	1,603
30	1,615	1,627	1,639	1,651	1,663	1,675	1,687	1,699	1,701	1,723
31	1,735	1,746	1,758	1,770	1,781	1,793	1,805	1,817	1,829	1,841
32	1,853	1,865	1,878	1,890	1,903	1,915	1,928	1,940	1,953	1,965
33	1,978	1,990	2,002	2,014	2,027	2,039	2,051	2,064	2,076	2,088
34	2,100	2,113	2,126	2,139	2,152	2,165	2,178	2,191	2,204	2,217
35	2,230	2,243	2,256	2,269	2,282	2,295	2,308	2,321	2,334	2,347
36	2,360	2,373	2,387	2,400	2,414	2,427	2,441	2,454	2,468	2,481
37	2,495	2,508	2,522	2,535	2,549	2,562	2,576	2,589	2,603	2,616
38	2,630	2,645	2,660	2,675	2,690	2,705	2,720	2,735	2,750	2,765
39	2,780	2,795	2,810	2,825	2,840	2,855	2,870	2,885	2,900	2,915
40	2,930	2,945	2,960	2,975	2,990	3,005	3,020	3,035	3,050	3,065

1/ 16.3-foot logs.

The six steps in constructing volume tables by the form-diameter method are as follows:

Step 1. For each d.b.h. and log-height group, tabulate the breast-height diameters, the top diameters (inside bark) and board-foot volumes of measured logs, and the total scale of the trees, as shown in table 11. (The Scribner scale is read from table 46.)

Step 2. By referring to table 10, making sure to use the section applying to the correct log-height group, determine the form diameter of each tree of every d.b.h. and log-height group. For example, the first of the 3-log trees in table 11 has a volume of 411 board feet. In table 10 the form diameter corresponding to this height and volume is shown to be 20.1 inches exactly. Similarly the form diameter of the third tree in table 11 is found to be 19.6 inches, since the volume of 387 board feet, corresponding to that form diameter, is approximately identical with this tree's volume, 386 board feet.

Step 3. For each d.b.h. and log-height group of sample trees, compute (a) average d.b.h. and (b) average top diameter of the first 16-foot log. For 2-, 3-, 4-, or 5-log trees, compute (c) average form diameter. For the data presented in table 11, these values are 20.0, 15.8, and 19.4 inches, respectively.

Step 4. Tabulate all the computed averages as indicated in table 12. Column 2 shows average diameter at the top of the first log (16.3 feet above stump) for each d.b.h. group of sample trees. Each of these top diameters is an average for 25 trees. Columns 3, 4, and 5 show the average form diameters, determined separately for each d.b.h. and height group in step 3. Each average in columns 3, 4, and 5 is based on 25 trees.

Step 5. Plot these tabulated averages over the corresponding breast-height diameters as shown in figure 5, presenting average top diameter of first 16-foot log by d.b.h. group, and figure 6, presenting average form diameters for the 2-, 3-, and 4-log height groups. With each plotted point representing 25 trees, there will be no difficulty in drawing the form-diameter curves. Curves such as those in figure 6 will nearly always be straight lines.

Step 6. Finally, read curved values from figures 5 and 6 for each d.b.h. and tabulate these values as in table 13. From the Scribner table (table 46, appendix) and table 10 determine the board-foot volumes corresponding to the tabulated diameters, and enter these volumes in columns 3, 5, 7, and 9. For example, the first value in column 3 is 42 board feet, the Scribner scale of a 9-inch log 16 feet in length. The second value in column 7 is 476 board feet, the scale of a 3-log tree having a form diameter of 21.5 inches (see table 10). This step completes the preparation of a volume table by the form-diameter method.

Table 11.--Specimen calculation of form diameters, for red gum

(D.b.h. group, 20 inches. Height group, 3 logs.)

Tree (number)	D.b.h. outside bark	Diameter inside bark at height above stump of --			Scribner volume of log number --			Total volume	Form diameter
		16.3 feet	32.6 feet	48.9 feet	1	2	3		
	Inches	Inches	Inches	Inches	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Inches
1	20.3	16.3	14.9	12.6	173	142	96	411	20.1
2	20.0	15.2	13.7	11.0	148	117	70	335	18.4
3	19.8	15.9	14.5	12.2	164	133	89	386	19.6
4	20.1	15.6	13.8	11.7	157	119	81	357	18.9
5	20.2	15.5	14.1	12.4	155	125	93	373	19.3
6	19.7	15.8	14.0	12.5	162	123	94	379	19.4
7	20.0	16.0	14.4	13.4	166	131	111	408	20.0
Average	20.0	15.8							19.4

Table 12.--Specimen summary of average form diameters, for red gum

D.b.h. group (inches)	Top diameter of first log	Form diameter, by log height		
		2 logs	3 logs	4 logs
	Inches	Inches	Inches	Inches
12	9.0	11.1		
16	12.5	15.1	15.4	
20	15.8	18.9	19.4	19.8
24	19.0	22.0	23.4	24.0
28	22.2	26.6	27.8	28.5
32	25.4		31.8	33.2
36	28.1			37.4
(1)	(2)	(3)	(4)	(5)

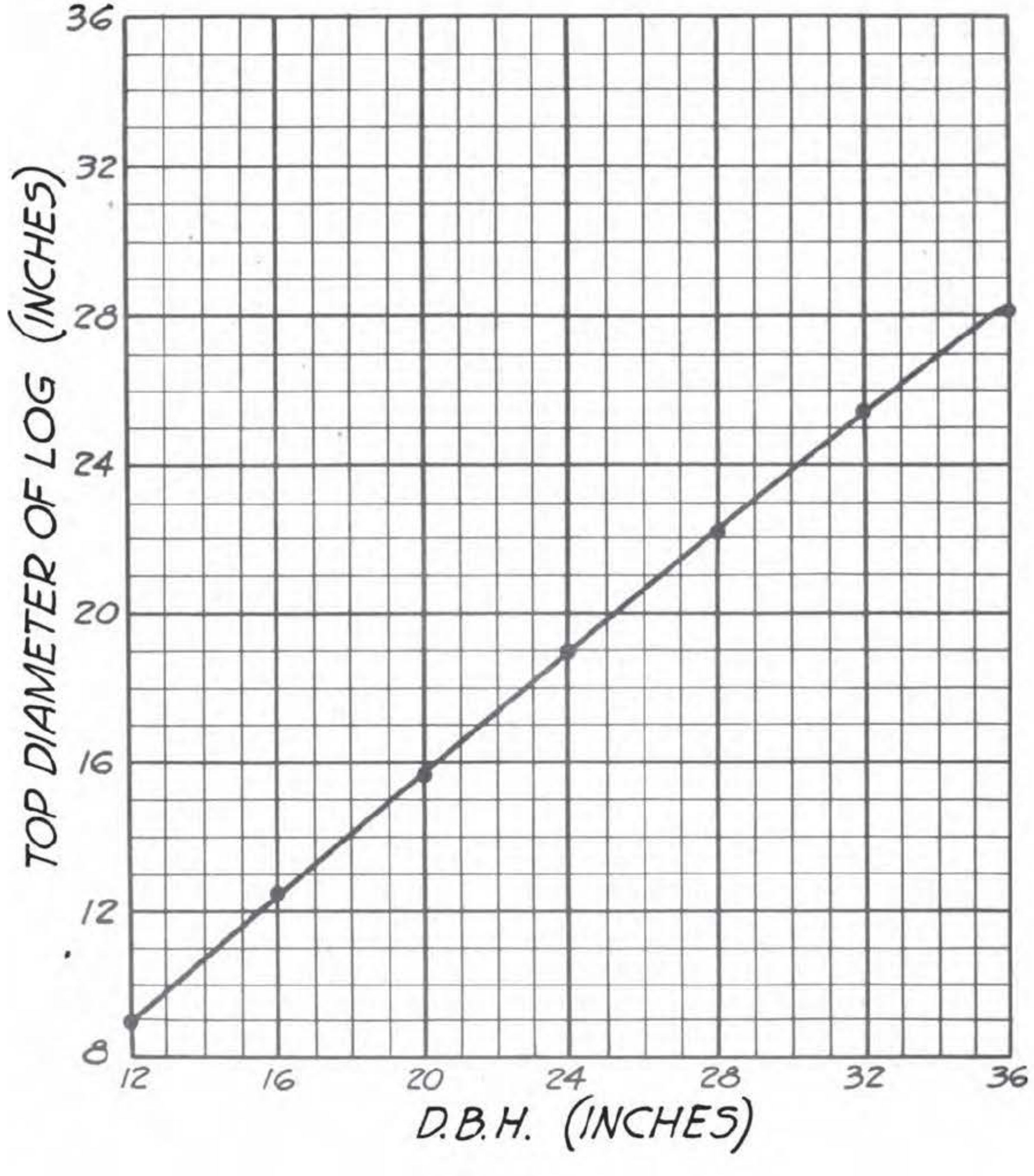

FIGURE 5 - AVERAGE TOP DIAMETER OF FIRST 16-FOOT LOG

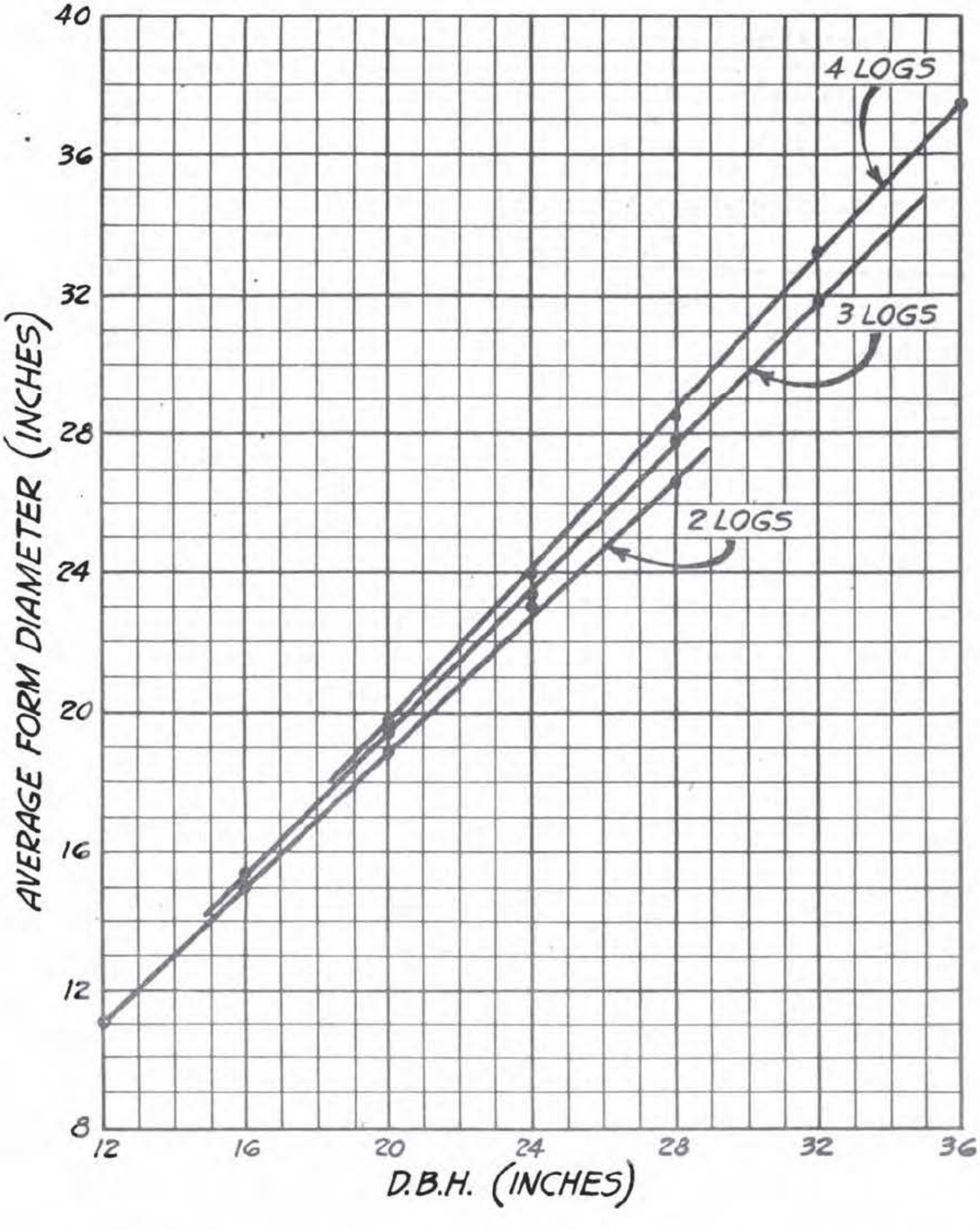

FIGURE 6 - AVERAGE FORM DIAMETERS FOR TREES CONTAINING TWO TO FOUR LOGS EACH

Table 13.--Specimen tabulation of volume[1] by d.b.h. and by log height, for red gum

D.b.h. (inches)	Top diameter and volume of first log		Form diameter and volume of trees containing --					
			2 logs		3 logs		4 logs	
	Inches	Bd. ft.	Inches	Bd. ft.	Inches	Bd. ft.	Inches	Bd. ft.
12	9.0	42	11.1	69				
13	9.8	52	12.1	88				
14	10.7	65	13.0	105				
15	11.5	77	14.0	127	14.3	181		
--	--	--	--	--	--	--	--	--
22	17.3	198	20.8	324	21.5	476	22.0	588
--	--	--	--	--	--	--	--	--
27	21.4	315	25.8	528	26.7	768	27.6	980
--	--	--	--	--	--	--	--	--
36	28.2	569	--	--	--	--	37.4	1,840
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

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[1] Scribner.

Before any volume table is used it should be thoroughly checked, unless it is to be applied in the same locality in which the samples used in preparing it were taken. In some cases a check is somewhat difficult to make, because no logging operations are in progress in the locality. If a considerable number of windfalls are present, these serve the purpose. It does not require very many trees to determine whether or not the table is reasonably close.

Naturally, every forest mensurationist desires to have his tables check as close to the basic data as possible. It should be remembered, however, that the trees measured are not the only ones for which the table is being made. Also, the process of measuring board-foot volume on logging operations is not minutely accurate; the scaled volume may vary from the actual volume by as much as 2 percent for sound timber, and as much as 6 percent for defective timber. There is no justification, therefore, for worrying and laboring over fitting curves and trying to reduce the difference between the volume-table scale and the actual scale to a very small fraction of 1 percent. It should be remembered that a cruise checking within 5 percent is considered unusual, and that one checking within 10 percent is considered good. It would seem better, therefore, to concentrate on eliminating some of the large errors due to other causes, and not spend a great deal of time trying to limit the so-called aggregate difference of the volume table to the minimum. The writers believe that for valuable species the volume tables should check within 1 or 2 percent of the basic data. If reasonable care is exercised in constructing volume tables and in curving the results, this accuracy will be achieved without much difficulty.

The largest errors made in cruising are due to the following: (1) Failure to obtain representative samples of the timbered area cruised; (2) failure to estimate heights correctly, particularly if the volume table is based on height to a fixed top; (3) failure to estimate diameters correctly; and (4) failure to establish sample plots or strips correctly. Errors in estimating tree diameters are about as common as errors in estimating the radii of sample plots. The former are less serious than the latter, because they usually compensate each other to a greater degree. A good cruiser is just as likely to overestimate diameter as to underestimate it. Many tests have shown that experienced men can estimate the average diameter of 100 or more trees within 1 percent of the true value, or even closer. This gives an error in volume of only about 1 to 3 percent.

This is the most important test for all volume tables: How will the volume calculation based on the table check out when the timber is actually cut? Even if a table checks within one-tenth of 1 percent of the basic data, this does not guarantee that the volume utilized will check close to the estimated scale of standing trees. In general, if volume tables check within 1 or 2 percent when applied to actual stands of valuable species, and within 2 or 3 percent when applied to stands of low-value species, they may be considered adequate.

Merits and Modes of Application of Different Types of Table

D.b.h. and Height to a Fixed Top. If the theory of construction only is considered, volume tables based on a fixed top are certainly as accurate as any others, especially in the case of coniferous species. This has been shown many times by different forest mensurationists. There is probably less variation in volume to a fixed top than in volume to the actual merchantable top. Errors in application, however, make this type of volume table less satisfactory than some others. Tables of this type, if made to a 6-, 8-, or 10-inch top, are of no value whatever for most of the hardwoods. In hardwood stands, only occasional trees can actually be utilized to a diameter such as 6 or 8 inches inside bark. Even when dealing with conifers, cruisers find it very difficult to estimate consistently just where such assumed top diameters are located on the tree stem. Tables of volume to a fixed top are fairly satisfactory for small trees of coniferous species running from two to three 16-foot logs in merchantable height. But what about timber running seven to nine logs per tree, or Douglas fir, which often runs from twelve to fourteen 16-foot logs per tree? It is impossible to estimate the 8-inch point in such trees with any degree of accuracy.

Tables based on a fixed top have often been checked on logging operations on the basis of a large number of cut trees. Such checks have often shown that the volume table was within 1 percent or less of the actual scale. This has been thought to prove that the table was very satisfactory and should be used. This type of check, however, has practically no value, since it is not a check on the accuracy of application. The best way to test the accuracy of application of a table based on a fixed top is to estimate the volume of, say from 20 to 50 standing trees, keeping a record of the estimated length of each tree from the stump to the fixed top, and then cut the trees and measure them. When experienced cruisers have individually estimated the same trees to a top of 6 or 8 inches, they have often found that their results differed widely, especially in timber running from five to eight 16-foot logs in height. Also, tests have shown that the estimates are generally low.

As an example, assume that an estimate of old-growth northern white pine is being made by use of table 6, Part II, Volume Tables for the Important Timber Trees of the United States, 3/ and that a 20-inch tree having a length of five 16-foot logs to a 6-inch top is tallied as a 4-log tree. The top log of the 5-log tree, being 6 inches in diameter, scales only 20 board feet. The error in estimate that results from missing this log, however, is 100 board feet, the total difference in scale between a 4- and a 5-log tree of this diameter. This error is 22 percent of the correct total. The additional volume in the 5-log tree is made up of the top log and slightly greater volume in all the other logs of the tree. If a 32-inch tree having a length of seven 16-foot

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3/ U. S. Dept. Agr., Forest Service. 1925.

logs to a 6-inch top is tallied as having a length of six logs, according to this table the error in the estimate is the difference between 1,750 board feet and 1,430 board feet, or 320 board feet, which is more than 18 percent of the higher value. Such errors are often made, because it is very difficult to determine the point of the fixed top, particularly in tall trees. As a rule, errors in estimating length to a fixed top are not compensating. The tendency is to underestimate. These two examples illustrate the importance, when using volume tables that are based on a fixed top, of going as close as possible to the exact top upon which the tables were based.

The actual limit of merchantability is determined chiefly by the position, number, and size of limbs and by irregularities of the tree stem. In the case of small smooth trees, it is determined in part by the smallest log size acceptable for lumber, ties, or other products. What cruisers want is a volume table showing the volume of merchantable sawlogs that can actually be cut from trees of different diameters. From the cruiser's point of view, the usable height may be defined as the height above the stump (usually 1 to 2 feet high) to either the minimum top utilization diameter or the point where the stem divides into large branches. The point representing the limit of merchantability can be determined by the cruiser with a much greater degree of accuracy than a fixed top. Different experienced men pick this point almost uniformly. The most able timber cruisers, when they estimate the number of logs in a given tree, do not think about a fixed top or any other top; they size up the tree and then judge how many logs it would be practical to take out of it.

If volume tables based on a fixed top are used, the following procedure is necessary to apply them correctly: (1) Measure enough cut trees in each diameter class to determine average length from the tip to the fixed top on which the tables were based, and plot a curve of this length over d.b.h. or prepare a table showing it by diameter class, for field reference; (2) measure the volume of the unused top for a sufficient number of trees in each diameter class to determine the percentage of volume between the fixed top and the used top. To check his judgment of height to the fixed top the cruiser carefully measures with the Abney level the total height of sample trees and, by referring to the table derived in step 1, makes the necessary deductions from total height and compares the result with his estimate. If a sufficient number of sample trees are carefully measured, there is no reason why fairly good results cannot be obtained in this way with volume tables based on a fixed top; but such studies require considerable time.

D.b.h. and Merchantable Height. The main argument against volume tables based on d.b.h. and merchantable height is that men with little experience do not know anything about the limits of merchantability and, therefore, cannot use such tables satisfactorily. It is true that a man cannot draw the line between merchantable and unmerchantable material with any degree of certainty unless he has had training. However, men trained in the fundamentals of timber-cruising methods, even without field experience, can be taught in a short time to recognize the limits of merchantability much more accurately than they can be taught to estimate height to a fixed top.

Utilization of certain species is fairly uniform over large regions; this has been definitely proved by many detailed logging and milling studies. There are, of course, wide differences in practice between individual operators, but top utilization on a great majority of operations falls close to the regional average. Local practices in some cases may cause volume utilized to vary widely from volume classed as merchantable, if only those logs are considered merchantable that will return their full share of the costs of operation and of marketing the product. Only detailed logging and mill-scale studies can determine which logs will do this. In cruising, also, the results of such studies cannot be given more than approximate application, because it is not practical to appraise each tree or doubtful log; that is a job for an expert logging engineer. Even if this were possible, compliance would depend upon the ability of the average crew of sawyers to interpret the information obtained through the studies. The accuracy of a cruise of merchantable volume, therefore, depends on recognizing the local utilization practice. This local practice and the factors responsible for it can easily be learned.

There are two very practical ways for beginners to learn to recognize the limits of merchantability as determined by actual utilization practice in the locality in which the cruise is to be made: 1. Visit logging operations, estimate the merchantable volume of standing trees, and then measure the logs cut from these trees. Repeat this many times, and make notes on the factors that limit utilization, such as crook, large limbs, and decay. The writers have trained beginners to do this, and have observed that within a few weeks all the men in training were turning in acceptable estimates. 2. Go into the woods with an experienced cruiser and take a course of training under his guidance. The senior author has had wide experience in giving this kind of training, and his observations definitely indicate that beginners, if they are truly interested in the work, can be taught in a short time to recognize the limits of merchantability accurately enough for all practical purposes.

D.b.h. and Total Height. Tables based on d.b.h. and total height can be applied to coniferous species much more accurately than tables based on d.b.h. and height to a fixed top, because total height can be measured more accurately. Unless modified to take site quality into account, however, they are not satisfactory for use on a tract of 160 acres or less, because it is not practical to measure enough sample trees to get a strong curve of height over diameter for such a small unit. If separate tables are made for different site qualities, and the site index is recorded for each sample plot, fair results can be obtained even on small tracts. On large areas, such as the units of several thousand to several million acres covered in the Nation-wide Forest Survey, tables based on total height give very satisfactory results.

In applying tables based on total height to very large areas, better results are obtained if the cruisers record only the diameters of the trees on strips or sample plots. This gives them more time for accurate determination of width of strip or radius of plot and of tree diameters. If only diameters are recorded, it is necessary for an expert to gridiron the area and take height measurements on a sufficiently large number of sample trees to make a strong curve of height over diameter. The volume tables based on total height can then be curved, and average volume for each diameter class can be read from the curves.

If it is not important to have a reliable cruise for each 40-acre tract, site quality determination for the area as a whole is sufficient.

D.b.h. Only. Tables based on d.b.h. only are very practical for application in estimating timber volume for large tracts, such as the units cruised in the Nation-wide Forest Survey, where an accurate estimate for any small area is not required. This type of table would be unsatisfactory for local application, because merchantable height varies too widely from place to place. When such tables are used, cruising is usually done by the line sample-plot method.

Tables of this character should be made by a man who is thoroughly familiar with the utilization practices in the region and with local factors of cull. Ordinarily they are based on net scale. About 300 to 1,000 trees for each forest condition and species are required to make a strong and reliable table. Separate consideration should be given to old growth and second growth and, in some cases, to portions of the stand differentiated by topography and site quality. For hardwood stands on rolling uplands and mountains, classification by site quality is very desirable; for hardwood stands on level bottoms, this may be unimportant. In some parts of the southern pine region, site quality varies little for many miles.

In the forest survey of the South, volume tables for individual species or groups of species were based on d.b.h. only. The procedure was to gridiron each area, or travel the roads that traversed it, taking sample plots at stated intervals and recording data on a sufficient number of sample trees for each 2-inch diameter class to make a strong curve of volume over diameter. More than 100,000 sample trees were taken for volume-table purposes, by men specially trained for this work. Estimated diameter, form class, taper, and merchantable height were recorded for each sample tree. Because the cruisers tallied only diameter, by species, without determining heights, the work was speeded up and they had much more time for determining accurately the diameters, the cull trees, and the areas of individual sample plots. The tables were checked from Texas to North Carolina and found to be reliable within 1 or 2 percent of the actual scale.

Cubic-Foot Volume Tables

In the general practice of timber estimating, cubic-foot volume tables are used chiefly to determine pulpwood or cordwood volumes, either of individual trees or of stands. Volume tables that give total cubic contents of trees from the ground to the very tip are of only occasional interest to cruisers; the most useful cubic-foot volume table is one that represents only the merchantable portion of the tree, from a given stump height, usually 1 foot, to a given top diameter outside bark, usually from 4 to 6 inches.

The cubic-foot volume of a tree is usually obtained by computing the volumes of individual short sections of the tree and then adding the computed volumes. Cubic-foot volume computations are much more accurate if based on lengths of about 2 to 4 feet than if based on lengths of about 10 to 16 feet. It is customary to scale the cubic volume of pulpwood or cordwood in 4-, 5-, or 8-foot sections.

The cubic-foot volume of any log or log section of a tree can be calculated by determining the cross-sectional areas, in square feet, corresponding to the diameters measured at the base and the top end of the section and multiplying their sum by half the length of the section in feet. (Areas corresponding to given diameters are shown in table 43, appendix.) For example, if the section is 8 feet long, its top diameter is 9.3 inches, and its base diameter is 10.2 inches, its volume is $(0.472+0.567)\ 4 = 4.16$ cubic feet. Another method is to measure the diameter at the middle of the section, read the corresponding cross-sectional area in square feet, and multiply this area by the length of the section in feet. Thus, if the middle diameter of an 8-foot log is 9.7 inches, corresponding to a cross-sectional area of 0.513 square feet, the volume of the log is $0.513 \times 8 = 4.10$ cubic feet.

The cubic-foot volume of the top section of a tree's stem, above the last log, is determined by multiplying the cross-sectional area at the base of the top section, in square feet, by four-tenths of the length of the top in feet. When the volume of all top branches above a certain minimum diameter is required, the volumes of the individual sections are computed separately by this method. The volume of the stump is usually considered that of a cylinder with a cross-sectional area equal to the stump's top area. The cubic-foot volume of the stump is the area of its top in square feet multiplied by its height in feet.

Construction Methods

There are several methods for preparing tables of merchantable cubic-foot volume. Most of these require much time and expert handling, and therefore will not be described here. A simple method will be presented here for constructing cubic-foot volume tables without computing volumes of individual sections of the tree. This method, in the opinion of the authors, is sufficiently accurate for all practical purposes of timber cruising.

In selecting sample trees, the cruiser should concentrate on a few of the breast-height diameter classes, and get at least 25 trees in each chosen class. For the general run of pulpwood species six diameter groups, such as 6, 8, 10, 12, 14, and 16 inches, will suffice for average pulpwood stands in the South, North, and Northeast.

Diameter measurements should be taken at points dividing the stem into approximately 5.8, 23.5, 33.8, 50.0, 66.2, 76.5, and 94.2 percent of its merchantable length, from stump to top. 4/ These seven points of measurement are distributed along the stem in such a way as to characterize its shape or form. When any of them falls on some abnormality such as a swelling or on a branch stub, two diameters should be taken, one above and one below the abnormality or stub, and averaged. Table 14 shows the points of diameter measurement in feet above stump for trees of different merchantable heights. If the merchantable height of a tree from a 1-foot stump to a top diameter of 4.9 inches outside bark, for example, is 48 feet,.then the first measurement is taken 3 feet above the stump, the second 11.5 feet above the stump, the third 16 feet above the stump, and so forth, as indicated in line 12 of table 14.

The basal-area factors (basal areas in square feet divided by 7) corresponding to given diameters in inches are shown in table 15.

The recommended method of tabulating the measurements is illustrated in table 16, the record for a 12.0-inch jack pine having a merchantable length of 48 feet. The points at which diameter outside bark was measured are indicated in column 1, and the measurements appear in column 2. By means of the Swedish bark punch, the average thickness of bark (doubled) was determined for each point of measurement, and the corresponding diameters inside bark were recorded in column 3. Next, the basal-area factors corresponding to these diameters (both outside and inside bark) were read from table 15 and entered in columns 4 and 5. When columns 4 and 5 were added up, separately, values called "form basal areas" were obtained. When these values were multiplied by the tree's merchantable height, 48 feet, total rough and peeled volumes were quickly obtained, thus: 0.4612 x 48 = 22.14 cubic feet, and 0.4130 x 48 = 19.82 cubic feet. If desired, such simple calculations of cubic-foot volumes can be carried out on the ground while the diameter measurements are being made.

4/ Gevorkiantz, S. R. Determination of Cubic Volume in the Field. Forest Research Digest, Lake States Forest Experiment Station, May-June, 1936. (Mimeographed.)

Table 14.--Points of diameter measurement for construction of cubic-foot volume tables

Merchant-able height (feet)	Points of measurement, in height above stump						
	1st	2nd	3rd	4th	5th	6th	7th
	Feet	Feet	Feet	Feet	Feet	Feet	Feet
20	1.0	4.5	7.0	10.0	13.0	15.5	19.0
25	1.5	6.0	8.5	12.5	16.5	19.0	23.5
30	1.5	7.0	10.0	15.0	20.0	23.0	28.5
32	2.0	7.5	11.0	16.0	21.0	24.5	30.0
34	2.0	8.0	11.5	17.0	22.5	26.0	32.0
36	2.0	8.5	12.0	18.0	24.0	27.5	34.0
38	2.0	9.0	13.0	19.0	25.0	29.0	36.0
40	2.5	9.5	13.5	20.0	26.5	30.5	37.5
42	2.5	10.0	14.0	21.0	28.0	32.0	39.5
44	2.5	10.5	15.0	22.0	29.0	33.5	41.5
46	2.5	11.0	15.5	23.0	30.5	35.0	43.5
48	2.8	11.3	16.2	24.0	31.8	36.7	45.2
50	3.0	12.0	17.0	25.0	33.0	38.0	47.0
52	3.0	12.0	17.5	26.0	34.5	40.0	49.0
54	3.0	12.5	18.5	27.0	35.5	41.5	51.0
56	3.5	13.0	19.0	28.0	37.0	43.0	52.5
58	3.5	13.5	19.5	29.0	38.5	44.5	54.5
60	3.5	14.0	20.5	30.0	40.0	46.0	56.5
62	3.5	14.5	21.0	31.0	41.0	47.5	58.5
64	3.5	15.0	21.5	32.0	42.5	49.0	60.5
66	4.0	15.5	22.5	33.0	43.5	50.5	62.0
68	4.0	16.0	23.0	34.0	45.0	52.0	64.0
70	4.0	16.5	23.5	35.0	46.5	53.5	66.0
72	4.0	17.0	24.5	36.0	47.5	55.0	68.0
74	4.5	17.5	25.0	37.0	49.0	56.5	70.0
76	4.5	18.0	25.5	38.0	50.5	58.0	71.5
78	4.5	18.5	26.5	39.0	51.5	59.5	73.5
80	4.5	19.0	27.0	40.0	53.0	61.0	75.5
82	5.0	19.5	27.5	41.0	54.5	62.5	77.0
84	5.0	20.0	28.5	42.0	55.5	64.0	79.0
86	5.0	20.0	29.0	43.0	57.0	66.0	81.0
88	5.0	20.5	29.5	44.0	58.5	67.5	83.0
90	5.0	21.0	30.5	45.0	59.5	69.0	85.0

Table 15.--Basal-area factors to be used in computing cubic-foot volume

Diameter (inches)	Basal-area factor,[1] by additional tenths of an inch of diameter									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.
1	0.0008	0.0009	0.0011	0.0013	0.0015	0.0018	0.0020	0.0023	0.0025	0.0028
2	.0031	.0034	.0038	.0041	.0045	.0049	.0053	.0057	.0061	.0066
3	.0070	.0075	.0080	.0085	.0090	.0095	.0101	.0107	.0113	.0119
4	.0125	.0131	.0137	.0144	.0151	.0158	.0165	.0172	.0180	.0187
5	.0195	.0203	.0211	.0219	.0227	.0236	.0244	.0253	.0262	.0271
6	.0281	.0290	.0300	.0309	.0319	.0329	.0339	.0350	.0360	.0371
7	.0382	.0393	.0404	.0415	.0427	.0438	.0450	.0462	.0474	.0486
8	.0499	.9511	.0524	.0537	.0550	.0563	.0576	.0590	.0603	.0617
9	.0631	.0645	.0659	.0674	.0688	.0703	.0718	.0733	.0748	.0764
10	.9779	.0795	.0811	.0827	.0843	.0859	.0875	.0892	.0909	.0926
11	.0943	.0960	.0977	.0995	.1013	.1030	.1048	.1067	.1085	.1103
12	.1122	.1141	.1160	.1179	.1198	.1217	.1237	.1257	.1277	.1297
13	.1317	.1337	.1358	.1378	.1399	.1420	.1441	.1462	.1484	.1505
14	.1527	.1549	.1571	.1593	.1616	.1638	.1661	.1684	.1707	.1730
15	.1753	.1777	.1800	.1824	.1848	.1872	.1896	.1921	.1945	.1970
16	.1995	.2020	.2045	.2070	.2096	.2121	.2147	.2173	.2199	.2225
17	.2252	.2278	.2305	.2332	.2359	.2386	.2414	.2441	.2469	.2497
18	.2524	.2553	.2581	.2609	.2638	.2667	.2696	.2725	.2754	.2783
19	.2813	.2842	.2872	.2902	.2932	.2963	.2993	.3024	.3055	.3086
20	.3117	.3148	.3179	.3211	.3243	.3274	.3306	.3339	.3371	.3403

Table 16.--Specimen tabulation of tree measurements

Locality: Itasca County, Minn., T. 149 N., R. 27 W.

Type: Red pine Site: Good

Recorder: E. K. Date: 7/15/26

Height above stump (feet)	Diameter		Basal-area factor1/		Notes
	Outside bark	Inside bark	Rough wood	Peeled wood	
	Inches	Inches	Sq. ft.	Sq. ft.	
3.0	12.3	11.0	0.1179	0.0943	Tree No. 17
11.5	10.5	10.0	.0859	.0779	
16.0	10.2	9.8	.0811	.0748	Species: J.P.
24.0	9.2	9.0	.0659	.0631	D.b.h.: 12.0 inches
32.0	7.9	7.6	.0486	.0450	Merch. hght: 48'
36.5	7.0	6.8	.0382	.0360	Stump hght: 1'
45.0	5.5	5.3	.0236	.0219	Top diam.4.9",o.b.
Form basal area			.4612	.4130	
Cu. vol.			2/22.14	2/19.82	
(1)	(2)	(3)	(4)	(5)	(6)

1/ Basal area divided by 7.

2/ Form basal area multiplied by merchantable height.

Table 17.--Summary of form basal areas and merchantable heights for a 6-inch d.b.h. group

Tree (number)	D.b.h.	Form basal area		Merchantable height
		Rough wood	Peeled wood	
	Inches	Square feet	Square feet	Feet
1	6.0	0.1305	0.1050	16
2	6.3	.1445	.1140	20
3	6.4	.1505	.1180	24
4	6.4	.1490	.1220	24
5	5.9	.1210	.0967	12
Total	31.0	.6955	.5557	96
Average	6.2	.1391	.1111	19

Table 18.--Specimen tabulation of merchantable cubic-foot volume (rough wood)

D.b.h. (inches)	Volume, by merchantable height[1]								
	8 feet	16 feet	24 feet	32 feet	40 feet	48 feet	56 feet	64 feet	72 feet
	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
6									
8									
10			8.11						
12					18.40				
14									
16									

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[1] Height above a 1-foot stump to a minimum top diameter outside bark of 4.0 inches.

The office work of preparing a table of merchantable cubic-foot volume consists in three simple steps:

Step 1. Prepare for each d.b.h. group a summary tabulation of d.b.h., form basal area for both peeled and unpeeled wood, and merchantable height, such as table 17. Compute totals and averages for each of the three columns and record them as shown.

Step 2. Prepare a graph such as figure 7 by plotting the average form basal areas of each summary table over the corresponding average d.b.h. value. Drawing such curves is not difficult, as the average values always show a definite trend.

Step 3. Convert the form-basal-area curves directly into a volume table by multiplying the form basal areas read from these curves by each merchantable height. For example the average volume, including bark, of a tree 10 inches in d.b.h. and having a merchantable height, to a 4-inch top, of 24 feet is 0.338 square feet (the value read from the curve OB at 10 inches) multiplied by 24 feet, or 8.11 cubic feet. The corresponding volume inside bark is 0.277 square feet (curve IB at 10 inches) multiplied by 24 feet, or 6.65 cubic feet. Average merchantable volume of rough wood for a 12-inch and 40-foot tree is 0.460 square feet x 40 feet = 18.4 cubic feet. The computed volumes are tabulated as in the partially completed volume table shown as table 18.

Step 3 may be omitted, since figure 7 is in itself a volume table, requiring only simple multiplication for determining merchantable cubic-foot volume for trees of any dimensions. Volumes even for such odd sizes as 9.3 inches d.b.h. and 51 feet merchantable height may readily be determined as 0.30 square feet x 51 feet = 15.3 cubic feet of rough wood and 0.24 square feet x 51 feet = 12.2 cubic feet inside bark.

In measuring more than 100 trees chosen at random from a locality for the purpose of preparing a volume table, the cruiser obtains fairly reliable data on average merchantable heights of trees by d.b.h. class. When these average heights are curved on cross-section paper over the average diameters to which they correspond (as a 19-foot height is shown in table 19 to correspond to a diameter of 6.0 inches), a definite curve is obtained that should represent the average run of timber on the tract. In cruising cordwood stands, by means of sample plots or by other methods, the cruiser gets a chance to see whether the curve of heights obtained from his volume-table measurements actually represents the average run of the cruised timber. This he can do by measuring with an Abney level the merchantable heights of a certain number of standing trees, mechanically selected on the line, and recording these measured heights directly on the same cross-section paper on which the curve of heights has already been drawn. Should the new points scatter equally on each side of the curve, the cruiser may justly assume that the curve represents the average run of heights of all trees on the tract. Should the new points, on the other hand, indicate a need for certain alterations in the trend of the curve, these changes can easily be made without much loss of time. The cruiser should not make such changes, however, unless he knows to what top diameter trees are actually utilized in the region, and is certain that he can estimate height to a merchantable top accurately; and he should make no correction in any part of the curve unless he has made at least 10 new observations in each diameter group and the new observations consistently fall below or above the curve.

When the cruiser has established a reliable curve of merchantable height over diameter, he can prepare a simple table showing the average merchantable cubic-foot content of trees of different diameters, such as table 19. In this table, the values in columns 1 and 2 were read from the height-over-diameter curve, the form-basal-area values were transferred from curve OB, figure 7, and the products of the values in columns 2 and 3 were entered in column 4 as average volumes of rough wood corresponding to the diameters in column 1. This local volume table can be used directly on cruise tallies of the species represented.

Table 19.--Specimen local cubic-foot volume table

D.b.h. (inches)	Merchantable height	Form basal area (rough wood)	Merchantable volume
	Feet	Sq. ft.	Cu. ft.
6	19	0.130	2.47
7	25	.177	4.42
8	30	.227	6.81
9	35	.280	9.80
10	40	.338	13.52
11	44	.397	17.47
12	47	.460	21.62
13	50	.527	26.35
14	53	.597	31.64
15	55	.670	36.85
16	57	.745	42.46
(1)	(2)	(3)	(4)

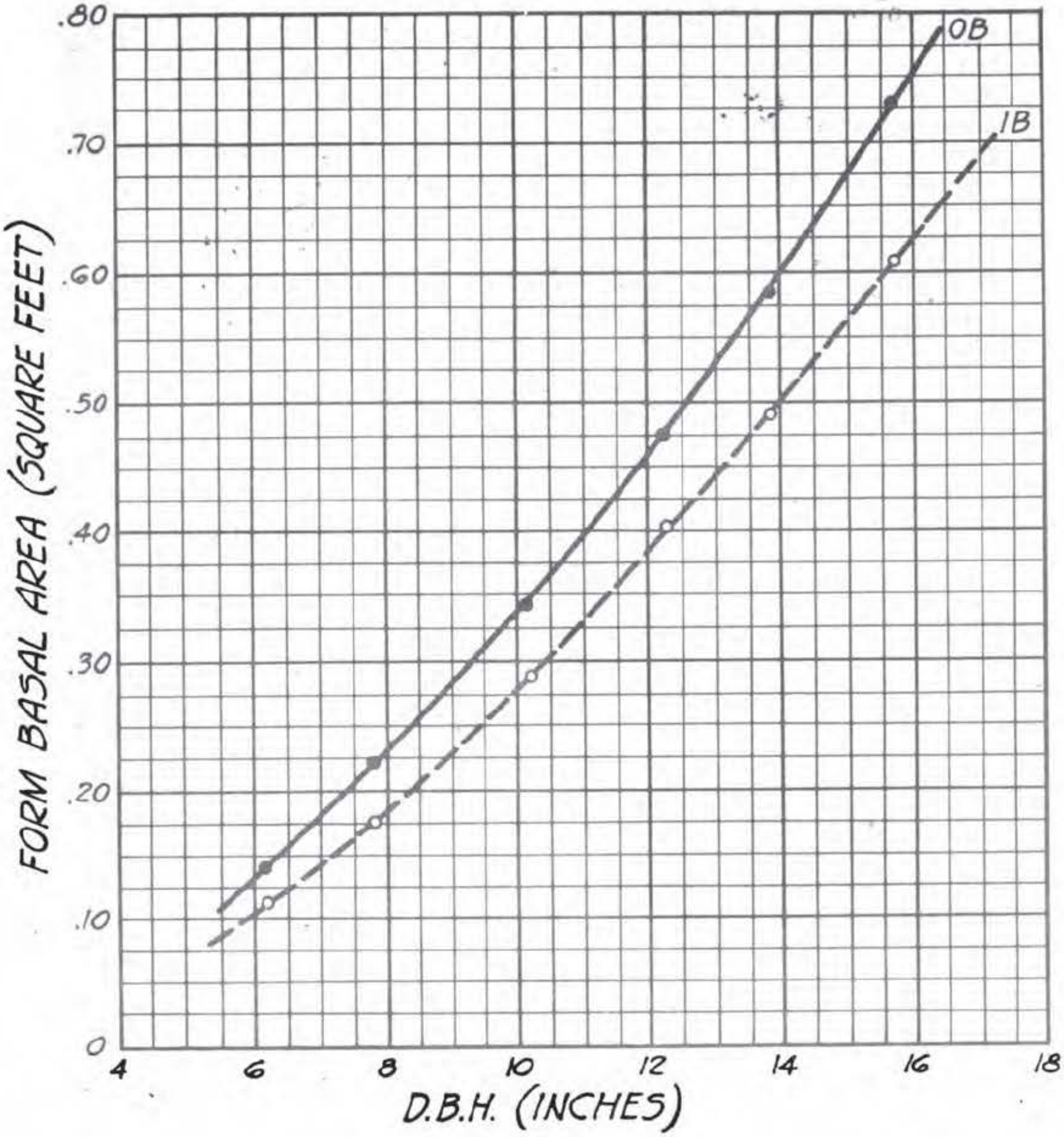

FIGURE 7 - AVERAGE FORM BASAL AREAS

OB = ROUGH WOOD IB = INSIDE BARK

The same method can be used in preparing local tables of total cubic-foot volume, i.e., volume including both stump and top. In that case, column 1 figures of table 14 are interpreted not as merchantable heights but as total heights, and the points of measurement indicated in table 14 are not above stump but above ground level. Table 15 is used the same way as before. In preparing the graph corresponding to figure 7, it is recommended that trees be classified not only by d.b.h. but also by total height, and d.b.h. values be plotted separately for each height class. Should no relationship appear between form basal area and total height, i.e., if no separate curves of form basal area over d.b.h. could be drawn for different height classes, all data would be combined into one curve.

Cordwood Converting Factors

Estimates of cubic volume of wood are usually expressed in terms of the standard cord, 4 by 4 by 8 feet, which occupies a total space of 128 cubic feet but usually contains not more than two-thirds of this quantity of solid wood unless the bark was stripped off before the bolts were piled.

Most of the pulpwood species, for example spruce, balsam fir, and jack pine, produce, as a rule, fairly smooth and straight bolts. When reasonable care is exercised in piling them the bolts stack up in about the same manner, and the standard cord of unpeeled wood contains in the neighborhood of 88 cubic feet. (This does not allow for settling, or for shrinkage or other losses.) Ordinarily the number of 8-foot bolts (100 inches long, to be exact) per cord of rough wood may be determined by use of the simple formula

$$N = \left\{ \frac{45}{d} \right\}^2 ,$$

in which d is the middle diameter of the bolt, outside bark, and N is the number of bolts required to make up a cord. Thus, the number of unpeeled bolts 100 inches long and having a middle diameter of 5 inches required to make a standard cord is $\left\{ \frac{45}{5} \right\}^2 = 9^2 = 81$; and the number per cord of such bolts having a middle diameter of 9 inches is $\left\{ \frac{45}{9} \right\}^2 = 5^2 = 25$. To get the number of 4-foot bolts, these results should be multiplied by 2.

Although this rule is accurate enough for all practical purposes where straight bolts are piled with reasonable care, the cruiser should check it from time to time as opportunity permits. It should not be difficult for him to do this every time he visits a pulpwood cutting operation. When the rule has been checked and found applicable to the timber in question, the cruiser can easily prepare a set of converting factors that will enable him to translate his tally summaries directly into standard cords. The process is illustrated in table 20.

The values in column 2 of table 20 are the diameters corresponding to form basal areas presented in table 19, as determined by use of the basal-area table in the appendix (table 43). The values in column 3 were computed by the formula

$$N = \left[\frac{45}{d}\right]^2$$

, values of column 2 being used for the factor d. The values in column 4 are merchantable heights given in table 19 divided by 8. The values in column 5 were computed by dividing the values in column 3 by the corresponding values in column 4.

Table 20.--Specimen calculation of number of trees per standard cord of unpeeled wood

D.b.h. (inches)	Middle diameter of average bolt	8-foot bolts per standard cord	8-foot bolts per tree	Trees per standard cord
	Inches	Number	Number	Number
6	4.9	84.3	2.38	35.42
7	5.7	62.3	3.12	19.97
8	6.5	47.9	3.75	12.77
9	7.2	39.1	4.38	8.93
10	7.9	32.4	5.00	6.48
(1)	(2)	(3)	(4)	(5)

If, for example, the cruiser's tally shows a total of 400 trees 7 inches in breast-height diameter on the sample plots used, he finds from table 20 that they will make about $\frac{400}{20} = 20$ cords of rough wood.

He can check this by other methods. Table 20 shows that the number of 8-foot bolts contained in a 7-inch tree averages 3.12, and table 19 shows that the volume of these bolts averages 8 x 0.177 = 1.416 cubic feet. Since it takes 62.3 of these bolts to make a cord (table 20, column 3), a cord of such bolts scales 62.3 x 1.416 = 88.2 cubic feet. Again, since a 7-inch tree has a merchantable volume of 4.42 cubic feet (table 19, column 4), it requires $\frac{88.2}{4.42}$ or about 20 such trees to make a cord of rough wood.

Allowance for Cull, Settling, and Shrinkage

It is necessary for every cruiser using tables of merchantable cubic-foot volume or cordwood volume to make certain deductions based on his own judgment and knowledge of the species and of local utilization and scaling practices. As a general rule, very little rot is found in second-growth stands of southern pines, in second-growth stands of yellow poplar and Virginia pine in the Appalachian region, or in spruce, jack pine, Norway pine, and northern white pine stands of the Lake States, eastern Canada, and New England. Balsam fir, aspen, and cottonwood have considerably more rot than the species just mentioned. In some regions deductions are made not only for rot but also for crook and for settling and shrinkage of cordwood piles. Deductions for settling and shrinkage average from 5 to 8 percent. The necessary deductions must be carefully calculated and applied to gross estimates of volume before a cruiser can hope to make his final estimates check satisfactorily.

General Converting Factors

Even in a pile of straight cylindrical bolts, about 19 cubic feet is air space. Because of uneven taper, which makes it difficult to pile bolts in perfect formation, on the average 11 cubic feet in addition is lost in piling. Thick short bolts pack better than slender long ones. Such factors as crookedness and roughness further reduce the solid content of a stack. When bolts are peeled and their knots are trimmed close, as a rule they pack slightly better.

The variation in solid content of the stacked standard cord is presented in table 21. The approximate cubic-foot values per cord of wood and bark shown by the table are very useful in practice. Application of the information in the table to actual problems is very simple. It requires only an approximate knowledge of how, when a stand has been cut for pulpwood or cordwood, its merchantable cubic-foot volume is distributed as regards the various characteristics and specifications of bolts shown in the table. Both the classification of the material and the estimate of the relative proportions of different kinds of material should be made in a very general way, as in the accompanying example.

Table 21.--Solid content of the stacked cord of unpeeled wood[1]

Character of bolts	Volume per standard cord of bolts of indicated length having middle diameters of --					
	Less than 6 inches		6 to 12 inches		More than 12 inches	
	4-foot	8-foot	4-foot	8-foot	4-foot	8-foot
	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.	Cu. ft.
Softwoods						
Straight						
Smooth..........	90	88	95	93	100	98
Slightly rough..	88	85	93	91	98	96
Slightly rough and knotty....	84	80	91	88	96	94
Not straight						
Slightly crooked and rough.....	80	76	88	84	93	91
Considerably crooked.......	76	72	85	80	90	87
Crooked, rough, and knotty....	70	65	79	75	83	80
Tops and branches	67	60	-	-	-	-
Hardwoods						
Straight						
Smooth..........	85	82	91	88	98	95
Slightly rough..	82	78	89	86	96	93
Slightly rough and knotty....	78	73	85	82	92	90
Not straight						
Slightly crooked and rough.....	75	70	82	79	89	86
Considerably crooked.......	70	65	79	75	85	82
Crooked, rough, and knotty....	67	60	75	70	78	75
Tops and branches	58	50	-	-	-	-

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[1] Forest Research Digest, Lake States Forest Expt. Sta., May 1935. (Mimeographed.) Values shown are for the standard cord, 4x4x8 feet.

Example of Application of Information in Table 21

Stand

Mixed hardwoods, cordwood size. Merchantable volume, 15,220 cubic feet. Cordwood cut in 8-foot bolts and piled unpeeled.

Computations

Character of material	Proportion of total volume	Volume per cord	Product
	Percent	Cu.ft.	Cu.ft.
Small tops and branches.	10	50	500
Medium-sized bolts. Considerably crooked.	70	75	5,250
Large bolts. Straight, slightly rough.	20	93	1,860
	100		7,610

Average factor (cubic feet per cord) $= \frac{7,610}{100} = 76.1$

Gross cordwood volume $= \frac{15,220}{76.1} =$ 200 cords.

Reduction for cull and settling = 10 percent.

Net cordwood volume = 200 x 0.9 = 180 cords.

Bark volume per cord amounts to about 12 cubic feet for birch, aspen, spruce, and balsam fir, 14 cubic feet for pines, ash, and basswood, 16 cubic feet for sugar maple and hemlock, and as much as 20 to 25 cubic feet for some species such as old-field loblolly pine in the Coastal Plain region. For volume inside bark of these species, therefore, the volumes per cord shown in table 21 should be reduced by these quantities.

Volume of Tree Tops

In the hardwood regions, after the best portions of tree stems are utilized for sawlogs the remaining large tops are frequently cut up into small chunks and sold for fuel wood. This is especially common around farm settlements. The determination of volume of tops in trees of different dimensions is a very tedious job; and few timber estimators will bother to get such information, even if they need it, thinking that a very rough guess will do. A "better-than-a-guess" method for determining volume of wood in tops of hardwood trees is presented in table 22. The table shows the approximate total cubic volume of cordwood bolts, 4 inches or more in top diameter, obtainable from tops of hardwood trees of different dimensions.

For a simple example of the application of table 22, assume a hardwood tree 30 inches in diameter at breast height and 83 feet tall. Suppose that only two 16-foot logs can actually be utilized from this tree above a 2-foot stump. This leaves a top having a length of 83 - (2 x 16 + 2) = 49 feet. From the basal-area table (table 43, appendix) we find that the cross-sectional area at breast height is 4.91 square feet. Multiplying 4.91 by 49 gives the dimension factor 240. Referring to table 22, we see that a tree top having a dimension factor of 240 contains on the average about 76 cubic feet, or about 1 cord, of wood.

Table 22.--Cubic volume[1] of hardwood tops

Dimension factor[2]	Average volume of top	Dimension factor[2]	Average volume of top
	Cu. ft.		Cu. ft.
10	2	120	33
20	4	140	39
30	6	160	46
40	9	180	53
50	11	200	61
60	14	220	68
70	17	240	76
80	20	260	84
90	23	280	92
100	26	300	100

[1] Table based on 800 carefully measured tops of red, pin, post, black, and bur oaks, black walnut, hickories, elm, and ash in Kansas and Missouri.

[2] The product of tree basal area (in square feet) at breast height and average height (in feet) of top above last sawlog.

CHAPTER 10. RULES OF THUMB FOR DETERMINING VOLUME

Board-Foot Volume

Several simple and fairly reliable rules of thumb for determining the board-foot volume of standing trees have been developed, but none of these, so far as the writers know, has hitherto been recorded and explained, and thus made readily available for use. A few of the simplest and most practical will be given here.

The great value of a practical, reliable rule is that it enables beginners to figure volume quickly on the ground and thus develop timber sense and judgment. A criticism lumbermen, loggers, and private cruising firms have often made of foresters is that they generally know very little about tree volume or about volume of timber per acre. This criticism is often justifiable. The fault is not in the young forester but in the method of training, which has not given him the best opportunity to develop himself. If a young forester or cruiser tallies diameters and merchantable heights but it is left to someone else to figure up the volumes in the office, he does not learn much about timber. Of course he has to observe diameters and heights, but he does not see the trees in the sense of lumber content. Volume tables are too mechanical to arouse the same interest that can be aroused by a rule. If 20 trees are tallied in one diameter class and all these trees have the same merchantable height, according to the volume table each of them has identically the same volume. Of course, this is not true; there may be a variation of 10 to 20 percent among these individual trees, because of differences in form. If the cruiser has some rule that is based on correct principles, and can determine by observation the variations in form and taper and their effect on volume, his job becomes much more interesting.

Form-Class and Taper Method

The form-class and taper method of estimating the volume in standing trees as described here was originated by the senior author 30 years ago, but was not used to any great extent until the beginning of the Nation-wide Forest Survey, in 1930. The reliability of estimates of tree volume made by this method has been definitely proved in many cases by carefully measuring cut trees and standing trees. To test it some 5,000 trees were climbed in the South, and at least 4,000 in the Lake States. The method is very valuable for checking the reliability of volume tables.

As was already explained, "form class" here means the ratio of the top diameter inside bark of the first 16-foot log to d.b.h. outside bark. If a certain tree is 30 inches in diameter outside bark at breast height and 24 inches in diameter inside bark at the top of its first 16-foot log, its form class is $\frac{24}{30}$, or 0.80. To calculate the top diameter of logs above the butt log, the taper is estimated. This method could be adapted, of course, to 10-, 12-, or 14-foot logs.

This method of estimating the volume of standing trees is not very practical for tree species that have a merchantable length of more than five or six 16-foot logs. Taper cannot be estimated with satisfactory accuracy for very tall timber. For this reason use of the form-class and taper method of estimating volume has been largely limited to the timber in the South, the Middle West, the Lake States, the Appalachian region, and the Northeast, and timber of corresponding merchantable height in the Pacific Northwest.

Stands of old-growth slash pine in ponds in the South, for example, are very uniform as to form class and taper. It has been found from careful measurements of cut trees in such stands in different parts of Florida, Georgia, and Alabama that their form class is about 0.82 to 0.83, and that the taper is about 1.3 to 1.4 inches in the second log, 1.6 to 1.7 inches in the third log, and 2.0 to 2.5 inches in the fourth log. These figures represent the general average; variations from the average occur, of course, in all stands. In most stands the form class ranges from about 0.78 as the minimum to about 0.86 as the maximum. Ordinarily, taper above the first log is strongly correlated with form class. It is usually greater than average in trees of low form class and less than average in trees of high form class.

General averages of form class and taper, by d.b.h., for certain timber species are presented in the appendix (table 38).

To train himself to estimate the volume of individual trees by the form-class and taper method with a reasonably high degree of accuracy, the cruiser should proceed as follows:

1. Observe as closely as possible the general form and taper of the standing trees.

2. Measure a sufficient number of cut trees to determine the average form class and taper accurately. Diameter at breast height is measured with a diameter tape or calipers and recorded to the nearest tenth of an inch. Diameter at the top of the first 16-foot log is determined in the same way, converted to diameter inside bark by subtracting double bark thickness, and recorded to the nearest tenth of an inch. The top diameter of the second log is determined and recorded in the same way.

3. From these measurements determine the spread between the high and low form classes.

4. Go back into the woods and, by studying the stand, learn to recognize the trees representing the average form class and average taper. This can be done by sizing up one standing tree after another and then checking the estimates of form class and taper by actual measurement after the trees are cut.

In this way it is possible to develop within a comparatively short period the judgment needed to recognize easily at least the average trees.

If no cut trees or windfalls are available, tree climbers, diameter tape, and a Swedish bark punch can be used to make reliable checks. One man after climbing to a height of about 18 feet lowers a tape, and the man on the ground holds the end of it at what he judges to be a logical stump height.

All estimating is done in relation to the average tree. If a cruiser has no standard to refer to he cannot say from looking at a standing tree whether the taper in the second 16-foot log is 1.6 inches or 1.8 inches; but if he has a clear picture in his mind of the tree of average form and taper, he can readily recognize even slight differences in taper and estimate the actual taper remarkably close.

When form-class is multiplied by the d.b.h. of the tree the top diameter of the first log inside bark is obtained. When the taper of the second log is subtracted from the top diameter of the first log the top diameter of the second log is obtained. The top diameters of the third and fourth logs, etc., are obtained in a similar manner. With the use of a log-rule table the volumes of the logs are determined, and the sum of these volumes is the saw-log volume of the entire merchantable portion of the tree.

Diameter-Factor or Form-Point Method

In the diameter-factor or form-point method, the diameter of the average 16-foot log in a tree is estimated as a percentage of the d.b.h. The scale of the average log is then multiplied by the number of logs in the tree to compute total volume. For example, if a longleaf pine tree 20 inches in d.b.h. contains five 16-foot logs and the top diameter of the average log is 14 inches (70 percent of d.b.h.), the Scribner scale of the average log is 123 board feet and that of the tree is 615 board feet. This method of computing volume on the ground and testing the reliability of volume tables works very satisfactorily in certain regions. Its use is limited to conifers, because of the extreme variability of top utilization in hardwoods in given d.b.h. classes. Top utilization by diameter class is fairly uniform for several of the coniferous species.

The diameter-factor rule will not, of course, work for trees from which only the butt log or the first two logs are to be utilized.

Southern Pines. On most operations in average stands of southern pine the top utilization diameter averages close to 50 percent of the diameter at breast height outside bark, being approximately 60 to 65 percent of d.b.h. in small trees, 50 to 55 percent in medium-sized trees, and 35 to 40 percent in large trees. Average top utilization diameters of old-growth stands of southern pines are shown in table 23. In general, in such stands a 12-inch tree is utilized to a 7- to 8-inch top, a 20- to 24-inch tree to an 11- to 13-inch top, and a 40-inch tree to a 14- to 16-inch top. (A diameter of 40 inches is attained by only one of the southern pine species, loblolly pine.) In old-growth stands of longleaf and shortleaf pine, if the trees are very old and have large limbs and wide-spreading crowns, the top utilization diameter sometimes averages close to 60 percent of d.b.h. It averages that high in many stands of old-field pine; old-field timber is usually rough and limby, and top utilization is therefore less close in it than in forest-grown timber except in localities where timber is scarce. In dense stands of medium-aged southern pine having long, smooth trunks and fairly small limbs, top utilization diameter usually averages somewhat less than 50 percent of d.b.h.

In old-growth stands of southern pine the diameter inside bark of the average 16-foot log in a tree is seldom less than 70 percent or more than 72 percent of the d.b.h. outside bark. In trees 24 inches in d.b.h., for example, the average 16-foot logs have diameters of from 16.8 to 17.3 inches. For 24-inch trees containing four 16-foot logs each the Scribner scale ranges approximately from 740 to 780 feet, and the Doyle scale ranges approximately from 670 to 700 feet. In second-growth stands of southern pine the diameter of the average 16-foot log in a tree is from 68 to 72 percent of the d.b.h., varying with the top utilization diameter. If the volume of the 127 longleaf pine trees for which data are given in table 7 is computed on the basis that the diameter of the average log in each tree is 70 percent of the d.b.h., the result checks within 1 percent of the actual scale.

Ponderosa Pine. The average top utilization of ponderosa pine closely approximates that of the southern pines. Measurements of trees on many operations in Idaho, Montana, Oregon, and Washington showed that the top utilization diameter for ponderosa pine averages close to 50 percent of d.b.h., and ranges in general only from 46 to 60 percent of d.b.h. Average top utilization diameters for ponderosa pine according to the practice in Montana and in Oregon are shown in table 24. In some instances 20-inch trees are utilized to a 12-inch top, 30-inch trees to a 15-inch top, or 40-inch trees to an 18-inch top. In such instances, the diameter of the average 16-foot log ranges from 66 to 68 percent of the d.b.h.

On this basis a ponderosa pine tree 30 inches in diameter outside bark at breast height, containing six 16-foot logs, scales about 1,600 to 1,700 board feet, Scribner rule. In old-growth stands of ponderosa pine, in which the ratio of top utilization diameter to d.b.h. averages close to 50 percent, ranging from 60 percent for small to medium-sized trees to 35 to 40 percent for large trees, the diameter of the average log in a tree averages close to 67 percent of d.b.h. If a diameter factor of 67 percent is applied to the 95 ponderosa pine trees for which data are given in table 3, the volume thus computed checks within 1 percent of the basic data. This 67-percent factor will work for almost any site index. Cruisers can easily learn to recognize stands in which the diameter of the average log per tree is 66 to 68 percent of d.b.h.

Table 23.--Top utilization of old-growth southern pines

D.b.h. (inches)	Average top utilization diameter, by species and location			
	Shortleaf pine		Longleaf and loblolly pine in South Carolina	Longleaf pine in Mississippi and Louisiana
	Mississippi and non-mountainous Arkansas	Arkansas mountains		
	Inches	Inches	Inches	Inches
10	7.0	7.0	7.0	7.0
12	8.0	8.0	7.0	8.0
14	8.5	8.5	8.0	9.0
16	9.0	9.0	9.0	10.0
18	9.5	10.0	10.0	11.0
20	10.0	11.0	11.0	12.0
22	11.0	12.0	12.0	13.0
24	11.5	12.5	13.0	13.5
26	12.0	13.0	13.0	14.0
28	13.0	14.0	-	14.5
30	14.0	15.0	-	15.0

Table 24.--Top utilization of ponderosa pine

D.b.h. (inches)	Average top utilization diameter		D.b.h. (inches)	Average top utilization diameter	
	Montana	Oregon		Montana	Oregon
	Inches	Inches		Inches	Inches
14	8.0	8.0	28	13.5	14.0
16	8.5	9.0	30	14.0	15.0
18	9.5	10.0	32	15.0	16.0
20	10.0	11.0	34	16.0	17.0
22	11.0	12.0	36	17.0	17.5
24	12.0	13.0	38	17.5	18.0
26	13.0	13.5	40	18.5	19.0

Western White Pine. The top utilization diameter of western white pine in northern Idaho, if the tops do not break in falling, runs about as follows: 10-inch trees (if such small trees are cut), about 60 percent of d.b.h.; 20-inch trees, about 40 percent; 30-inch trees, about 35 percent; and 40-inch trees, about 30 percent. For western white pine in Idaho the diameter of the average 16-foot log varies approximately from 61 to 65 percent of d.b.h. For 20-inch trees it averages about 65 percent of d.b.h. for 30-inch trees, about 63 percent; and for 40-inch trees, about 61 percent.

Douglas Fir. In the Douglas fir region of western Oregon and western Washington the top utilization diameter of Douglas fir ranges approximately from 40 to 45 percent of d.b.h. in large trees and to as much as 60 percent of d.b.h. in small trees--say, trees 20 inches in d.b.h. In large timber in that region the tops break in falling, and for this reason, in general, 70-inch trees are utilized only to a 26- to 32-inch top. On good ground the top utilization diameter of such trees is sometimes less than 26 inches, but on rough ground it is often greater than 32 inches. Top utilization diameters for Douglas fir in the Pacific Northwest are shown in table 25.

With this top utilization in Douglas fir, the diameter of the average 16-foot log in a tree varies approximately from 57 to 65 percent of d.b.h. It runs about 65 percent of d.b.h. for 20-inch trees, 60 percent for 30-inch trees, 57 percent for 44-inch trees, and 60 to 62 percent for 50-inch and larger trees.

Douglas fir volume computed by the diameter-factor rule checks out very close to the volume actually scaled in 32-foot lengths. It was figured for the average 16-foot log because in the Douglas fir region many cruisers use 16-foot log lengths if they tally diameters and merchantable height.

D.b.h.-Factor Method

In the d.b.h.-factor method, average log diameter is calculated by adding a given factor to d.b.h. and dividing the result by 2. This rule gives close results for many species, and it can be learned easily and applied rapidly. For example, for western white pine the given factor in this rule is 6 to 9. Assume that a western white pine containing five 16-foot logs has a d.b.h. of 20 inches. In this case diameter of average log $= \frac{20 + 6}{2} = 13$. A 16-foot log having a top diameter of 13 inches scales 100 board feet Scribner rule, uncurved. Therefore this tree is calculated by the d.b.h.-factor method to scale 500 board feet.

Table 25.--Approximate top utilization of Douglas fir in the Pacific Northwest

D.b.h. (inches)	Top utilization diameter	D.b.h. (inches)	Top utilization diameter	D.b.h. (inches)	Top utilization diameter
	Inches		Inches		Inches
20	11-13	38	16-18	56	23-24
22	11-13	40	17-19	58	24-25
24	12-14	42	18-20	60	24-27
26	12-14	44	18-20	62	25-28
28	13-15	46	19-20	64	26-29
30	14-16	48	20-21	66	26-30
32	14-16	50	21-22	68	27-31
34	15-17	52	22-23	70	27-32
36	15-17	54	23-24	72	27-32

Factors for calculating the diameters of average 16-foot logs for western white pine, ponderosa pine, Douglas fir, and western hemlock are given in table 26. It is very simple to figure out such factors for coniferous species. From 25 to 50 sample trees are sufficient for this purpose.

Cubic-Foot Volume

Some simple rules have been developed that facilitate considerably the construction of cubic-foot volume tables. The values given in table 27 have been found to approximate closely those of the average pulpwood or cordwood tree in second-growth stands of southern pines ranging from 6 to 16 inches in d.b.h. In using this table it is necessary to distinguish carefully among stands of high form, stands of average form, and stands of low form. It should be noted that the values apply to rough wood only.

If the basal area shown in table 27 as corresponding to the middle diameter of the average stick in a tree is multiplied by the tree's merchantable height in feet, the result is the number of cubic feet of rough wood in the tree. For example, assume that it is desired to determine the cubic-foot volume of a 10-inch tree of average form with a merchantable height of 40 feet. By reference to column 4 of the table, it will be found that the basal area of the average stick in such a tree is 0.340 square feet. This figure multiplied by 40 gives 13.6 cubic feet as the volume of rough wood.

Comparatively few stands of southern pine are of high form as defined in table 27. A great majority are of average form. This table applies also to yellow poplar and red gum; swamp black gum in the river bottoms of the South (if d.b.h. is taken above the swell); Virginia pine and other species of pine in the Appalachian region; spruce, balsam fir, jack pine, red pine, and white pine in the Lake States; spruce, balsam, and aspen in eastern Canada; and spruce, balsam, and paper birch in Maine and other New England States. It closely approximates the volume of many other species. The high-form values are applicable to most dense stands of aspen and white birch and to some spruce stands. Those for average form give close results for a large proportion of the spruce stands, and those for average and low form fit most of the jack pine stands. Which set of values best fits any given stand or species can be determined by carefully measuring the diameter of from 20 to 50 representative trees at breast height and at other points along the stem to 1/10 inch, computing the cubic-foot volume, and making use of the following formulas, in which "D" stands for d.b.h., "d" stands for middle diameter of average stick, and the other figures are constants:

High form $$d = \frac{900D - (3D)^2}{1{,}000}$$

Average form $$d = \frac{885D - (3D)^2}{1{,}000}$$

Low form $$d = \frac{860D - (3D)^2}{1{,}000}$$

Table 26.--Factors to be used in determining diameter of average 16-foot log in a tree

Species and d.b.h.	Factor	Species and d.b.h.	Factor
Western white pine		Ponderosa pine	
20 inches..............	6	20 inches..............	7
30 inches..............	8	30 inches..............	10
40 inches..............	9	40 inches..............	14
Douglas fir[1]		50 inches..............	16
20 to 30 inches.........	6	Western hemlock[2]........	8
32 inches or more......	4		

[1] Cruised to top utilization diameter of 11 to 12 inches for trees less than 30 inches in d.b.h., 12 to 15 inches for 30-inch trees, and 14 to 17 inches for larger trees.

[2] Top utilization diameter, 12 to 16 inches.

Table 27.--Values for calculating cubic-foot volume of rough wood in second-growth southern pines

STANDS OF HIGH FORM

D.b.h. (inches)	Percentage factor[1]	Middle diameter of average stick	Basal area of average stick	Sticks per cord[2]		Approximate top utilization diameter
				4-foot wood	8-foot wood	
		Inches	Sq. ft.	Number	Number	Inches
6	85	5.1	0.142	168	81	3.8 - 4.2
8	83	6.6	.238	101	48	4.0 - 4.4
10	81	8.1	.358	67	33	4.4 - 4.8
12	79	9.5	.492	48	23	4.8 - 5.2
14	77	10.8	.636	37	18	5.2 - 5.6
16	75	12.0	.785	31	15	5.6 - 6.2
STANDS OF AVERAGE FORM						
6	83	5.0	.136	175	85	3.8 - 4.2
8	81	6.5	.230	106	50	4.0 - 4.4
10	79	7.9	.340	69	34	4.4 - 4.8
12	77	9.2	.462	52	25	4.8 - 5.2
14	75	10.5	.601	39	19	5.2 - 5.6
16	73	11.7	.747	33	16	5.6 - 6.2
STANDS OF LOW FORM						
6	81	4.9	.131	181	88	3.8 - 4.2
8	79	6.3	.216	110	54	4.0 - 4.4
10	77	7.7	.323	71	36	4.4 - 4.8
12	75	9.0	.442	54	26	4.8 - 5.2
14	73	10.2	.567	41	20	5.2 - 5.6
16	71	11.4	.709	35	17	5.6 - 6.2

[1] Value by which d.b.h. is multiplied to obtain middle diameter of average stick.

[2] It is assumed that a cord contains 90 cubic feet of rough wood, and that the wood is fairly straight. An allowance of 5 percent is made for settling, shrinkage, etc.

The most practical procedure is as follows:

1. Measure about 10 trees in each diameter class.

2. Record the d.b.h., merchantable height, top diameter, and cubic-foot content of each tree.

3. Determine the sums of the diameters, merchantable heights, and cubic-foot volumes, respectively.

4. Divide the diameter total by the number of trees, thus obtaining the average d.b.h.

5. Divide the total cubic-foot volume by the total merchantable length, thus obtaining the basal area of the average stick (weighted by volume).

6. By reference to the three formulas, determine which best fits the stand.

Table 28 illustrates the calculations. In this case the average d.b.h. is $\frac{44.9}{7}$, or 6.41, and the basal area of the average stick is $\frac{28.7}{182}$, or 0.158. The average diameter that corresponds to this basal area (as shown by table 43, appendix) is approximately 5.4 inches. By reference to the formula for high-form timber, the diameter of the average stick is computed as follows:

$$\frac{900 \times 6.41 - (3 \times 6.41)^2}{1,000} = 5.399.$$

Dividing 5.399 by the average d.b.h. in inches, 6.41, gave the factor 0.84227, or 84.23 percent, which was applied to each d.b.h. shown in table 28 to get diameter of average stick. The basal areas corresponding to these diameters (read from basal-area table) were then multiplied in each case by the merchantable length of the trees in feet, with the result that the estimated cubic-foot volumes presented in column 6 were obtained. These showed that the high-form rule fitted the seven trees of the sample reasonably well.

It is not difficult to learn to make cubic-foot volume tables by this method. The characteristic form and taper of trees can be recognized after some practice in classifying trees in this respect and checking judgment by measuring the trees when they have been cut. After long and intensive training, it is possible to estimate the percentage factor with sufficient accuracy to make cubic-foot volume tables that check within 3 percent of the measured volume, which is close enough for many purposes. In one day two men can obtain the data needed to make a good local table, by estimating the diameters, percentage factors, and merchantable lengths of a sufficient number of trees and measuring a few trees to check the accuracy of the estimated percentage factors. One day is required to construct the table.

Table 28.--Specimen calculation to find what formula for middle diameter of average stick best fits a stand

Measured tree (number)	D.b.h.	Merchantable length	Actual volume	Top utilization diameter	Computed volume
	Inches	Feet	Cubic feet	Inches	Cubic feet
1	5.8	20	2.6	3.8	2.6
2	6.4	24	3.8	4.2	3.8
3	6.6	32	5.3	4.4	5.3
4	6.2	28	3.8	4.0	4.1
5	6.7	26	4.6	4.3	4.4
6	6.9	32	5.7	4.5	5.9
7	6.3	20	2.9	4.1	3.1
Total...	44.9	182	28.7		29.2

PART II

CHAPTER 1. ELEMENTS OF STATISTICAL ANALYSIS

Every timber cruiser should know how to deal with observational data; he should know how to collect data, how to reduce them to simple forms, how to determine their accuracy, and how to interpret their significance.

For many years observational data and statistics have been thoroughly studied. We now have a series of logical conceptions and analytical procedures embodied in the so-called statistical method. These are very useful in the solution of many practical problems and are indispensable in the interpretation of quantitative data. Their use has been adopted in practically every branch of learning. A full exposition of the statistical method would go far beyond the purpose of this publication; but an elementary discussion of the method is pertinent.

Statistics and the Population

Every object of inquiry possesses one or many distinctive characteristics that can usually be measured or expressed in numbers. These characteristics result, of course, from numerous causes. For example, the average diameter of trees in a forest stand reflects the combined effect of such factors as age, composition, and density of timber and quality of site. Each independent cause or factor contributes its share of variation to the total effect. One cause may either add to or completely counteract the effect of another.

A single observation has a very limited meaning. A statistical inquiry usually involves many observations. It consists largely in (1) classifying causes, (2) determining their effect, and (3) establishing the limits of variation in this effect. By classifying the observations into more or less distinct groups, the investigator makes them reveal the effects of individual causes or factors. For example, in preparation for estimating the volume of a given timber stand a cruiser can divide the stand into parts representing different site qualities. He can further divide each part into patches of different age classes, and can divide each of these patches into various density groups. Now, he will readily find that volume varies considerably less within each subdivision of the classified stand than it does in the stand as a whole.

A large number of individuals that might be included in some general classification is called a statistical universe or population. The finer the classification, the more homogeneous the population. In practice, it is usually difficult to make even the main conditions or circumstances of a classification exactly uniform; almost invariably, some causal factors are left uncontrolled or even overlooked. From the population we take samples, and from records of observations on the samples we determine the values that most probably characterize the entire population. A statistical inquiry boils down to classifying a large number of observations in a way that reveals their mean value and the degree of their variation.

The Mean and the Standard Deviation

The mean, or the arithmetic average, is the sum of the items divided by their number. As an illustration, let us take the records of merchantable heights shown in table 29.

The sum of all 37 items here is 1,221 feet. Their mean, therefore, is $\frac{1,221}{37}$ or 33 feet. This arithmetic average is the height around which the individual heights center. If the differences between the individual heights and the average are computed, the sum of the differences of the heights that are less than the average exactly equals the sum of the differences of the heights that exceed the average.

This record discloses a considerable variation among merchantable heights. The least and greatest heights are 16 and 49 feet. The total range of variation (49 minus 16), therefore, is as large as the average itself.

The simplest measure that can be used to express variation is the mean deviation. This is the average of the deviations of all individual values from the mean, taken regardless of whether deviations are plus or minus quantities. For example the deviations, plus or minus, of the heights in table 29 from their mean, 33 feet, are as shown in table 30. These deviations total 222 feet. The average deviation, then, is 222 divided by 37, or 6 feet.

A better measure of variation is the so-called standard deviation, or root-mean-square deviation. This is obtained by:

1. Taking the difference between each individual observation and the mean (as in table 30),

2. Squaring each individual difference,

3. Dividing the sum of the squares by the total number of observations less 1, and

4. Extracting the square root of the result.

The squares of the deviations shown in table 30 are presented in table 31. The sum of all these squares is 1,968; the total number of observations less 1 is 36; 1,968 divided by 36 is 54.67; and the square root of 54.67 is approximately 7.39. This value, 7.39 feet, is the standard

Table 29.--Specimen record of merchantable heights of trees

Tree (number)	Merchantable height	Tree (number)	Merchantable height	Tree (number)	Merchantable height	Tree (number)	Merchantable height
	Feet		Feet		Feet		Feet
1	16	11	24	21	26	31	35
2	34	12	39	22	25	32	34
3	34	13	23	23	34	33	36
4	42	14	25	24	30	34	42
5	27	15	40	25	30	35	40
6	44	16	41	26	31	36	38
7	28	17	35	27	30	37	40
8	39	18	36	28	49		
9	19	19	36	29	29		
10	22	20	32	30	36		
Total...	305	Total...	331	Total...	320	Total...	265

Table 30.--Deviations of tree heights shown in table 29 from their mean

Tree (number)	Deviation	Tree (number)	Deviation	Tree (number)	Deviation	Tree (number)	Deviation
	Feet		Feet		Feet		Feet
1	-17	11	-9	21	-7	31	+2
2	+1	12	+6	22	-8	32	+1
3	+1	13	-10	23	+1	33	+3
4	+9	14	-8	24	-3	34	+9
5	-6	15	+7	25	-3	35	+7
6	+11	16	+8	26	-2	36	+5
7	-5	17	+2	27	-3	37	+7
8	+6	18	+3	28	+16		
9	-14	19	+3	29	-4		
10	-11	20	-1	30	+3		
Total--	81	Total--	57	Total--	50	Total--	34

Table 31.--Squares of deviations shown in table 30

Tree (number)	Square of deviation	Tree (number)	Square of deviation	Tree (number)	Square of deviation	Tree (number)	Square of deviation
1	289	11	81	21	49	31	4
2	1	12	36	22	64	32	1
3	1	13	100	23	1	33	9
4	81	14	64	24	9	34	81
5	36	15	49	25	9	35	49
6	121	16	64	26	4	36	25
7	25	17	4	27	9	37	49
8	36	18	9	28	256		
9	196	19	9	29	16		
10	121	20	1	30	9		
Total--	907	Total--	417	Total--	426	Total--	218

deviation of the merchantable heights. The square of the standard deviation, in this case 54.67, is frequently termed the population variance.

When the mean of all observations falls near the middle of the range and the observations distribute themselves evenly or symmetrically on each side of the mean, the standard deviation is approximately 1-1/4 times the average deviation. In our example the standard deviation, 7.39 feet, is 1.23 times the average deviation, 6 feet.

The average deviation is seldom used in statistical work. The standard deviation is considered the only dependable index of variation, and is used almost universally.

The Frequency Distribution

When the number of observations is large, calculating the mean and the standard deviation as just described becomes burdensome. Instead, the observations are grouped by some conveniently chosen class interval and their so-called frequency distribution is determined. This process is the one universally used by foresters in tallying trees by d.b.h. class. For example, if the merchantable heights presented in table 29 are tallied by 5-foot intervals their frequency distribution is readily found to be as shown in table 32.

Table 32.--Frequency distribution of merchantable heights shown in table 29

Height class (feet)	Midvalue of class	Frequency
	Feet	Number
13-17	15	1
18-22	20	2
23-27	25	6
28-32	30	7
33-37	35	10
38-42	40	9
43-47	45	1
48-52	50	1
		37

Unfortunately, there is no definite rule as to how many classes should be used in calculating a frequency distribution. The number varies according to the character of the data. It should not, however, be less than 5 or more than 30. For less than 100 observations, 6 to 10 classes usually suffice. If there are more than 100 but less than 1,000 observations, from 10 to 15 classes may be used. With more than 1,000 observations it is customary to use from 15 to 25 classes. A very wide interval usually obscures the natural variation, and a very narrow interval usually is not warranted by the accuracy of measurement.

Ideally, the average of the observations in each class is identical with the midvalue of the class. Actually, this is the case only when each class includes a very large number of observations.

In some instances, frequency distributions are smooth and symmetrical. In some, one or more factors affect the occurrence of certain values in such a way that the frequency distribution is skewed and irregular. Whenever one or more independent factors exert a predominant influence on the observed characteristics, the observations tend to concentrate around the middle of the range, where the mean of the distribution is usually found, and to become less frequent toward the ends of the range.

The ideally symmetrical distribution, known as the normal frequency distribution, is regarded as the normal law of error and has a definite bearing on the theory of sampling. Ideally, when the frequencies on both sides of the mean are considered the distribution of the observations is as follows:

Range (standard deviations or standard errors)	Observations
	Percent of total
½	19.74
1	38.29
1½	54.67
2	68.27
2½	78.87
3	86.64
3½	91.99
4	95.45
5	98.76
6	99.73
7	99.95
8	99.99

The arithmetic mean is in the exact center of this distribution. Exactly half of each of the percentages is on either side of the mean. As a general rule, a range of 2 standard deviations (1 standard deviation on each side of the mean) includes about 68 percent, or two-thirds, of all observations, and a range of 6 standard deviations includes practically all observations.

Short-Cut Methods of Computing Arithmetic Mean and Standard Deviation

When frequency tables based on a sufficiently large number of observations are available, the mean and the standard deviation are commonly calculated by a short-cut method employing an assumed mean, illustrated in the following:

From the frequency distribution given in table 32, table 33 was constructed. The arbitrary mean used was 35 feet, approximately the midpoint of the range of merchantable height (column 2). The deviations of the midvalues of all the height classes from the assumed mean were entered, with the proper signs, in column 4. For example, the first class is 4 units below the fifth class, the midvalue of which was chosen as the assumed mean. Each deviation in column 4 was next multiplied by the corresponding frequency shown in column 3, and the products were entered in column 5. The squares of the deviations were recorded in column 6, and the products of these squares and their corresponding frequencies in column 7, and totals were computed.

Table 33.--Calculation of arithmetic mean and standard deviation by use of an assumed mean 1/

Merchantable height class (feet)	Midvalue of class	Frequency	Deviation	Deviation times frequency	Deviation squared	Deviation squared times frequency
	Feet	Number	Feet	Feet	Sq.feet	Number
13-17	15	1	-4	-4	16	16
18-22	20	2	-3	-6	9	18
23-27	25	6	-2	-12	4	24
28-32	30	7	-1	-7	1	7
33-37	35	10	0			
38-42	40	9	1	9	1	9
43-47	45	1	2	2	4	4
48-52	50	1	3	3	9	9
Total........		37		(-29) (+14)		87
1	2	3	4	5	6	7

1/ In this instance, 35 feet.

The arithmetic mean is calculated as follows:

1. We obtain the difference between the positive and the negative total in column 5, which is -15.

2. We multiply this difference by the height-class interval, 5 feet, obtaining the product -75.

3. We divide -75 by the total number of observations, 37, obtaining a result of approximately -2.03 feet.

We subtract 2.03 feet from the assumed mean, 35 feet (if the result of step 3 were positive we would add it), and find that the true arithmetic mean is 32.97, or practically 33 feet, the same value that was calculated from table 29.

The mean may be found also by multiplying the midvalue of each height class by the corresponding frequency, summing the products, and dividing the sum by the total number of observations. If this method is applied to the values given in table 33, for example, the sum of the products is found to be 1,220 feet, and by dividing 1,220 feet by 37 we get approximately 33 feet, the mean as determined before.

The standard deviation is calculated as follows:

1. Multiply the square of the class interval in table 33 by the total of column 7. The product of these values, 25 x 87, is 2,175 square feet.

2. Divide 2,175 square feet by the total number of observations less 1, or 36. The result is approximately 60.42 square feet.

3. Square the difference between the calculated mean and the assumed mean and multiply it by the number of observations. Squaring the difference between the means, 2.03 feet, gives the result 4.12 square feet, and multiplying this value by 37 gives the result 152.44 square feet.

4. Divide the product obtained in step 3 by the number of observations less 1, or 36. The result of dividing 152.44 square feet by 36 is 4.23 square feet.

5. Subtract the value obtained in step 4 from the value obtained in step 2. The difference is 56.19 square feet.

6. Extract the square root of this difference. The square root of 56.19 square feet is approximately 7.5 feet, and this is the standard deviation.

Coefficient of Variation

Sometimes we need a measure of relative dispersion of values independent of the unit of measurement employed. Such a measure is the coefficient of variation. This is the percentage ratio of the standard deviation to the arithmetic mean. For the records of merchantable height used here as an example, the coefficient of variation is $\frac{7.39}{33} = 0.224$, or 22.4 percent. This coefficient is used chiefly in comparing two sets of records as to variability. The magnitudes of the two sets of original records may be very different, so that the absolute values of the standard deviations are not comparable measures of variation. When the standard deviations are related to the arithmetic means, however, comparison becomes possible.

The Standard Error

The reliability of a single observation in a series is this observation's probability of differing from the arithmetic mean of the series by a certain quantity. Any deviation from the arithmetic mean can be expressed in terms of the standard deviation. We have just learned that a range of 2 times the standard deviation normally includes about two-thirds of all observations in a series; this means that normally the chance of any single observation to exceed the mean by as much as, or more than, one standard deviation is about 1 in 3. Statisticians have agreed to consider this probability as standard. The standard deviation of a series is, thus, an index of dispersion by means of which the probability of occurrence of certain individual values can be estimated. Since it expresses the average deviation of all observations, it is also considered as the standard error of a single observation.

Let us assume that sampling is repeated, so that several independent series of records become available, all representing the same population. All these series, of course, have slightly different means and standard deviations. An estimate based on all the series will be more accurate than an estimate based on any one of them. If the grand mean of all the series is taken as the true mean of the population, the individual means may be considered as independent estimates of the population and the differences between them and the grand mean as the errors of sampling. The individual means will form a frequency distribution of their own, just like the individual observations in any one series. The general spread of these means from the grand mean, however, will be considerably less than the spread of individual observations in any single series. The standard deviation of these means is called the standard error. Just as the standard deviation expresses the reliability of any single measurement in a series, the standard error expresses the reliability of the mean of the series.

The reliability of sampling is controlled primarily by the number of observations; as a rule, the precision of an estimate varies as the square root of the number of observations on which the estimate is based. If, therefore, we divide the standard deviation, or the standard error of a single observation, by the square root of the number of observations, we shall get an estimate of the standard error of the mean. This, fortunately, means that it is not always necessary to resort to repeated sampling in order to determine the standard error of the arithmetic mean. The standard deviation for any given population is considered constant. It stands to reason that any individual group of samples, or series, if reasonably large, should yield a fair estimate of it. If sampling is good, the standard error of the mean can be obtained by simply dividing the calculated standard deviation by the square root of the number of observations. For instance, in our sample of heights the square root of the number of observations is 6.08. Dividing the standard deviation of these heights, 7.39 feet, by 6.08, we obtain 1.215 feet, the standard error of the mean.

Although the individual observations in a sample seldom distribute themselves according to the normal law of error, previously stated, the means of independent samples taken at random 5/ closely conform to the probabilities implied by it; in other words, the means of such samples approximate the normal distribution of errors, regardless of the form of the frequency distribution of individual observations. From the normal distribution of errors we may say, therefore, that in our example the chance that the difference between the mean and the mean of any other series from the same population will equal or exceed 1.215 feet (a range of 2 times the standard error, considering both sides of the mean), is 1 in $\frac{100}{100 - 68.27}$, or about 1 in 3, and the chance that it will exceed 3 x 1.215 or 3.645 feet is 1 in $\frac{100}{100 - 99.73}$, or about 1 in 370.

Odds of 370 to 1 are considered very high. A range of ±3 times the standard deviation or standard error is frequently called the critical range. Any variation beyond this range is considered unquestionably significant. Deviations beyond the range of ±2 times the standard deviation or standard error (the range that normally includes 95.45 percent of all cases) may be considered statistically significant, since the odds against such deviations' occurring by chance are 22 to 1. This range, however, is considered the limit of significance.

When observations are taken not from the entire population but only from some essentially different parts of it, as a rule the true standard error of the mean is considerably larger than the ratio between the standard deviation and the square root of the number of observations. Much depends here, of course, on the variation between means of the different parts. When, on the other hand, the observations are taken proportionately from all the different parts of the population (each part being uniform within itself), the standard error of the mean is slightly less than when observations are taken at random. These points are considered more fully later.

5/ Random sampling is discussed later.

Estimates of the standard deviation, also, are subject to error. The standard error of the standard deviation in a normally distributed population is very nearly equal to the standard deviation itself divided by the square root of twice the number of observations. In our example, since the standard deviation of merchantable heights is 7.39 feet, the number of observations is 37, and the square root of twice 37, or 74, is 8.6, the standard error of the standard deviation is $\frac{7.39}{8.6}$ or 0.86 feet. This means that if additional series of samples were selected, the standard deviations of the additional trials would lie between 6.53 feet and 8.25 feet in 68 cases out of 100.

Number of Observations Necessary

In our example we found that the standard error of the mean of merchantable heights, based on 37 measurements, was in the neighborhood of 1.2 feet. It was pointed out that in rare instances a single estimate of the mean of a sample from the same population might exceed the mean of 33 feet by as much as $3\frac{1}{2}$ feet. Such a standard error may be considered too large for certain types of work. Suppose our work is of such nature that we wish the standard error not to exceed $1\frac{1}{2}$ feet: how many more observations should we take to ensure this accuracy? Using the odds of 22 to 1 against the occurrence of larger errors, we may set the standard error at 1/2 of the maximum error tolerated, that is, at 0.75 foot. Now, in order to determine what number of observations is required, all we need to do is to divide the square of the standard deviation by the square of the standard error. Squaring 0.75, we get 0.562. The square of the standard deviation is 54.67. Dividing 54.67 by 0.562, we obtain the value 97. For the desired accuracy of the mean, therefore, we need 60 additional measurements. For odds of 370 to 1 (a range of ±3 standard deviations), the number of observations we should need is $\frac{54.67 \times 3 \times 3}{1.5 \times 1.5}$, or 219.

Limited Population

The foregoing discussion applies to a series of observations that is a very small sample of the population. Sometimes, as in estimating timber on very small blocks, a sample comprises a substantial portion of the whole. In such a case the population is described as limited. Let us suppose that in our example, in which the merchantable heights of 37 trees were measured, only 55 trees were available for measurement. Under such conditions the standard error of the mean would be considerably less than the 1.2 feet computed here. To compute the standard error of the mean of a limited population, the square of the standard error computed on the assumption that the population is unlimited is multiplied by a correction factor representing the intensity of sampling, and the square root of the product is extracted. The correction factor is the difference between the total possible number of observations and the actual number of observations, divided by the total possible number of observations. In our example, the correction factor is $\frac{55 - 37}{55} = 0.327$. The square of the standard error calculated on the assumption that the population was unlimited, 1.215 feet, is 1.476 square feet. Multiplying 1.476 by 0.327, we get 0.483 square foot. Thus the standard error of the mean of this limited population is the square root of 0.483 square foot, or about 0.7 foot.

Use of the correction factor becomes unimportant as the factor approaches unity, that is, when the difference between the actual and the possible number of observations becomes very large.

Significance of Differences Between Means

We shall finally consider this typical problem: Two independent samples have been obtained. Their means differ by a certain amount. How small must this difference be to be considered statistically insignificant? We may take, for example, two independent records of merchantable heights. Measurement of our first sample, 37 trees, shows that the mean height is 33 feet, and that the standard deviation is 7.39 feet. Measurement of our second sample, 49 trees, in the same way, shows that the mean is 37 feet and the standard deviation is 6.25 feet. Is this difference of 4 feet between the means of the two samples so large as to exclude the possibility that the two samples have been obtained from the same population? If both sets of measurements were obtained from the same run of merchantable heights, then the question is: Could this difference have arisen from an error of random sampling?

When many pairs of independent samples are obtained from the same population, the differences between their means, too, form a normal frequency distribution. The mean of this distribution of differences is zero and the standard error of these differences is the square root of the sum of the squares of the standard errors of the two independent series of means. When we test the significance of the difference between any two means, we first assume that both samples have come from the same population and then we determine the probability of occurrence of differences as great as, or greater than, the one actually observed. If this probability is very small, we conclude that the two samples have not been obtained from the same population.

Referring now to the second sample of merchantable heights, we first determine its standard error. This is 0.893 foot (6.25 feet divided by the square root of 49). Squaring this quotient, we obtain the value 0.797 foot. When this value is added to the square of the standard error of our first sample, 1.476 feet, the total is 2.273 feet. The square root of 2.273 is about 1.5 feet, and this is the standard error of the difference.

We now see that the actual difference between the two means is practically 2-2/3 times its standard error, and is, therefore, considerable. According to the normal distribution of error, a range of 2 x 2-2/3, or 5-1/3, standard deviations should include about 99 percent of all cases. The odds against the occurrence of such large deviations near the limit of the range are 100 to 1. We conclude that something is wrong with the sampling or the two estimates would not have agreed so poorly. Perhaps in the second sample more trees were measured in patches of extra tall timber than was warranted by the general run of the merchantable heights within the entire stand.

CHAPTER 2. STATISTICAL THEORY OF SAMPLING

Timber cruising is essentially a sampling process. Its aim is to obtain information on the volume and quality of timber, which is known to vary from place to place within the boundaries of the forest tract. This information is obtained by examining only a portion of the whole, a procedure comparable to that used in determining the value of a carload of ore or the quality of a binful of wheat. No two tracts of timber exhibit precisely the same variation in volume or quality. Furthermore, the different forest conditions that cause variation in volume and quality are rarely distributed uniformly throughout an area, but rather occur in irregular and complex patterns. Timber estimating must rely, therefore, on some procedure such as representative sampling by means of plots or strips. What constitutes proper sampling? How should the different units in the cruise sample be chosen? How many such sampling units are required for a given degree of accuracy? The answers to these questions involve some knowledge of statistical principles, and should be clearly understood by men engaged in timber cruising.

Representative Sampling

Every forest tract, whether large or small, can be divided into many blocks, and each of these blocks can be divided into many units large enough for sample plots. For example, a 640-acre timber tract can be divided into 16 40-acre blocks and each of these blocks can be divided into 160 quarter-acre units. This will break up the entire tract into 2,560 units of sampling. The entire number of such units will form what is known in statistics as a population.

Sampling makes it possible to determine the mean of the population and to determine the degree of variation in volume among the individual sampling units. The latter is known as the population variance, and is determined, as was shown before, by averaging the squares of the differences between unit volumes and the population mean. The magnitude of the variations between the volumes of individual sampling units and the mean volume of the population controls the intensity of sampling needed. If a great proportion of the individual volumes differ widely from the mean, this indicates lack of uniformity in such factors as age, site quality, and density. If a great proportion of them differ only slightly from the mean, this indicates rather uniform timber conditions and implies that a more reliable final estimate can be expected to result from sampling of equal intensity than in the former case.

The statement that the units actually examined in a given instance represent the entire population, or all the units on the tract, means that the mean and the variance of the sample agree satisfactorily with the mean and the variance of the population. Whether the true values of the whole population are closely approximated by those of the sample depends, of course, primarily on the intensity of sampling and the method of selecting the samples.

Dividing the area into blocks as a preliminary to selecting sampling units achieves a twofold purpose. First, sampling each and every block provides a uniform coverage or representation of the area rarely attained under haphazard selection. Second, this affords an opportunity to separate the entire population into parts that are more or less homogeneous within themselves. This procedure is known as representative sampling. Ordinarily, the area is divided into blocks of equal size and the same number of samples is taken from each block. However, when it is definitely known that the population is composed of heterogeneous clusters of different shapes and sizes the blocks are adjusted to correspond roughly to these clusters and the number of samples is proportioned to the size of the block. If, for example, timber of a given age class occupies 10 percent of the total area, it is represented by 10 percent of the entire number of plots used. Under this arrangement, which is known as proportionate sampling, the sampling units vary less within each block than they do in the population as a whole. In general, the larger the number of blocks, the greater the chance that sampling units will be taken within all areas that deserve to influence the final estimate. Likewise, the larger the number of units actually examined within each block, the greater the reliability of sampling, since the accuracy of sampling is largely controlled by its intensity.

If a reliable map showing forest types, age classes of stands, density of stocking, etc., is available, proportionate sampling is facilitated. Such a map automatically divides the area into a number of blocks that are more or less homogeneous within themselves. Knowing the extent of the different blocks, one can take samples proportionately.

Random Selection of Samples

The selection of samples within each block should theoretically be made in such a way as to give each sampling unit in the population an independent and equal chance of being included in the sample. This means that if, for example, there are 100 sampling units in a block, every unit from 1 to 100 should be given the same chance of being selected and the choice of any one unit should not preclude the choice of any other, or in any way affect the equality of chances for the remaining 99 units. Ideally, therefore, the selection of samples should be made purely at random, or on the basis of chance.

The principle of random selection may be briefly illustrated as follows: Suppose 16 quarter-acre plots are to be selected at random from the 160 quarter-acre sampling units composing a forty. Tags numbered 1 to 160 (each number corresponding to the number of a sampling unit) are placed in a box and thoroughly mixed, then one tag is drawn and its number noted. Before the second and each of the succeeding 14 draws, the tag previously drawn is replaced in the box and the whole contents thoroughly mixed again. If the same tag is drawn more than once, it is replaced in the box without being recorded, and an extra draw is made. In this way every tag in the box, and likewise the corresponding sampling unit in the forty , has an independent and equal chance of being selected. All different patches of timber thus have an equal chance to be represented by this random selection in the same proportion that they bear to the whole area, regardless of their shape or size.

Mechanical Selection of Samples

The usual method of estimating timber, however, is to cross the tract a number of times, not at random but at regular intervals, measuring the trees either along a continuous narrow strip or on sample plots distributed at regular intervals along the line. This is called mechanical or systematic sampling. It is quite evident that should the timber volume of sampling units vary at random geographically, each equally spaced plot on the cruise line would, as in the case of random selection, have an equal chance of containing either high or low volume. Under these conditions, there would be no reason to expect any correlation between the plot volumes and the regular order in which the plots were taken. If, however, the units of high and of low volume, respectively, are not distributed at random over the area but rather tend to cluster or form narrow bands, the situation is somewhat different. With such arrangement of volumes, in mechanical sampling there is danger of placing some of the cruise lines along such narrow bands of either high or low volume and thus of overestimating the prevalence of that condition. As a precaution, so far as is practical the cruise lines are always placed across such definite bands or formations.

In a mechanical or systematic survey the spacing of sample plots should be controlled by the intensity of the cruise and made approximately the same in both directions. The reason for this is obvious. If, for example, the plots are close together along the survey lines and far apart in the other direction, narrow areas along the lines are very well sampled at the expense of the much wider areas enclosed between the lines. Furthermore, the accuracy of sampling is lowered by disproportionately increasing the degree of possible association that usually exists between plots taken close to each other. When, however, the spaces between both plots and lines are narrow because the intensity of cruise is high, this positive association, or correlation, between adjacent plots is usually compensated by negative correlations in the other direction. This explains the fact that it is customary to recommend staggering plots in relation to the plots on adjacent lines.

Mechanical vs. Random Selection of Samples

The random, or ideal, method of selecting samples involves serious practical difficulties in locating sample plots on an area. It requires, obviously, an excessive amount of walking from plot to plot, and for this reason is seldom used in the actual practice of timber estimating. Mechanical selection is a more expedient method. Mechanical or systematic sampling has another advantage. This method, when a sufficiently large number of samples are taken and when the samples are well spaced and so arranged that the lines always cut across the continuous patches of timber, is even more accurate than random sampling. It is wholly capable of producing reliable estimates of the population, since it represents the different patches of timber in the same proportion in which they occur on the cruised area, and is quite successfully used in the actual practice of timber cruising.

Mechanical sampling has one disadvantage. All recognized methods of determining the degree of precision, or the reliability, of sampling are based on the assumption that the samples are selected at random. The population variance estimated from samples obtained mechanically may easily be affected by a certain degree of dependence among the samples. For example, as has been mentioned before, when samples are taken in some regular order patches of either high or low volume tend to occur along the cruise lines more frequently than they would among samples selected by chance. When the sampling is carefully planned, however, so as to avoid such errors so far as possible, and when sample plots are evenly spaced, the variation among the individual samples is nearly the same as it would be under the conditions of random sampling. Although rarely exact, the variance estimate based on such carefully planned systematic sampling is satisfactory for all practical purposes as a basis for estimating the accuracy of the cruise.

Reliability of Sampling

What is meant by the reliability of sampling? Let us suppose, for the sake of illustration, that one has cruised a 5,000-acre timber tract 100 times, using for each cruise 400 quarter-acre plots randomly distributed over the area. It will be observed immediately that the results of the individual cruises, each constituting an independent estimate of timber on the same area, vary among themselves, falling either above or below the grand average of all the estimates. The logical way to determine the reliability of any one cruise is to determine the average spread of the individual estimates from the mean, or the degree of their dispersion. The best measure of this dispersion, as we already know, is the standard deviation of the cruise means, or standard error, calculated by (1) determining the difference between each individual cruise estimate and the general mean, (2) squaring each individual difference, (3) dividing the sum of the squares by the number of cruises less 1, and (4) extracting the square root of the result. This standard error is an index of the reliability of each of the 100 cruise estimates. The lower the standard error, the greater the reliability of the individual cruise.

The magnitude of the standard error of the estimates resulting from the independent cruises depends, of course, primarily on the number of sample plots employed in each cruise. With 800 plots instead of 400, each individual cruise would be more accurate and, consequently, the results of all the independent cruises would vary less among themselves.

As has been implied before, in defining the accuracy of a single cruise one usually thinks in terms of the probability of occurrence of errors of different magnitudes. From the distribution of estimates resulting from repeated trials, it is possible to determine what proportion of the total number of estimates may be expected to fall within any given range on either side of the average. In specifying the desired accuracy of a single cruise, therefore, one simply endeavors to define the probability of being wrong by a certain quantity which one sets as a limit. According to the law of error, as has already been explained, the error of sampling equals or exceeds the standard error once in 3 trials, equals or exceeds twice the standard error once in 22 trials, and equals or exceeds three times the standard error once in 370 trials. If the differences between individual cruise estimates and the mean of all estimates fall according to this general distribution, it is assumed that they are merely random errors of sampling.

In actual practice, of course, it is scarcely to be expected that anyone will run 100 independent cruises of the same tract in order to determine the sampling error of a cruise. As a matter of fact, no one ever needs to do so. In the method of sampling described here as representative the total variation of timber volume may be considered in two parts, the variation among blocks and the variation within blocks. If there is no significant variation among blocks, the blocks themselves may be regarded as random samples of the population and the error of sampling can be determined either from the mean variance among blocks or from the mean variance within blocks, since both variances will be nearly alike. If the variation among blocks is relatively great, this means that the population has been divided into parts differing from each other but essentially homogeneous within themselves.

In representative sampling like this, in which each block is sampled every time a new trial is made, the reliability of the estimated mean volume of the population depends only on the variation within each block, even if mean volume varies considerably from one block to another. In determining the standard error of the mean, therefore, consideration is limited to the variation within blocks, or the dispersion of volumes of individual sample plots from their respective block means. The measure of this variation is the standard deviation of the individual plot volumes, and the standard error of sampling is simply the quotient of this standard deviation and the square root of the total number of sample plots used.

Calculating the Reliability of Representative Sampling

For an example of the calculation of the standard error in representative sampling, take a 240-acre stand of spruce pulpwood. A 10-percent cruise is run, with quarter-acre plots. The area is divided into six 40-acre blocks, and from the 160 sampling units contained in each block 16 plots are selected at random. The distribution of the volumes of the plots in different blocks is shown in table 34.

These records are all that is necessary to compute the standard error of sampling. The procedure of computing the error is as follows:

(1) Obtain block totals by adding all plot volumes in each block separately. The totals (see table 34) are 48, 56, 88, 32, 96, and 64 cords.

(2) Divide each block total obtained in step 1 by 16, the number of plots per block. The block averages thus obtained are 3.0, 3.5, 5.5, 2.0, 6.0, and 4.0 cords.

(3) Obtain separately for each block the differences between individual plot volumes and the block mean. For instance, the first difference in block 1 is $3 - 2 = 1$ and the third difference in block 4 is $2 - 0 = 2$.

(4) Square each difference obtained in step 3.

(5) Add all the 96 squared differences obtained in step 4. The sum is 538. This is known as the "sum of squares within blocks."

(6) Obtain the difference between the total number of plots and the total number of blocks. This is the difference between 96 and 6, or 90.

(7) Divide the "sum of squares within blocks", obtained in step 5, by the difference obtained in step 6. The quotient thus obtained is known as the "mean variance within blocks." This variance is $\frac{538}{90}$, or 5.978.

(8) Extract the square root of the mean variance obtained in step 7. The result is the standard deviation of individual plot volumes, based on the combined variance of plots within all blocks. The square root of 5.978 is 2.445.

(9) Extract the square root of the total number of plots. The square root of 96 is 9.798.

(10) Divide the standard deviation obtained in step 8 by the value obtained in step 9. The result is the required standard error of the general mean. In our example it is $\frac{2.445}{9.798}$ or 0.2495 cord.

Table 34.--Distribution of plot volumes within different blocks of a 240-acre stand of spruce pulpwood

Sample plot (number)	Volume per plot in block number --					
	1	2	3	4	5	6
	Cords	Cords	Cords	Cords	Cords	Cords
1	2	0	5	0	5	0
2	4	3	5	0	9	0
3	5	5	6	0	7	6
4	1	5	6	1	4	0
5	3	4	7	1	10	4
6	4	6	8	3	9	0
7	4	5	2	2	6	6
8	1	4	1	1	6	8
9	1	2	9	0	4	0
10	1	3	7	4	6	1
11	4	6	6	0	3	6
12	6	2	2	6	3	6
13	4	2	10	4	9	10
14	3	4	6	4	5	10
15	0	4	5	3	4	7
16	5	1	3	3	6	0
Total.....	48	56	88	32	96	64
Average...	3.0	3.5	5.5	2.0	6.0	4.0

The general mean, or the average volume per plot, is found by dividing the total volume of all the plots, 384 cords, by the total number of plots, 96. The result is 4 cords per plot, or 16 cords per acre. The volume on the entire tract, therefore, is 240 x 16 cords, or 3,840 cords. If the standard error of the mean is 0.2495 cord per plot, or 6.24 percent, then the total error is 0.0624 x 3,840 cords, or 239.6 cords.

According to the normal law of error, only once in 3 trials will the estimate differ from 3,840 cords by more than 239.6 cords, only once in 22 trials will it differ by more than 479.2 cords, and only once in 370 trials will it differ by more than 718.8 cords. It has become customary to use 3 times the standard error as the limit of error permissible in sampling. This limit, rather than the standard error itself, is usually considered in specifying the accuracy of a cruise.

In proportionate sampling, the calculation of the standard error is based on the weighted variances of the different blocks. Again we may take an actual example. A 40-acre tract of mature northern white pine is made up of three distinct density groups. Well-stocked stands and under-stocked stands each occupy 25 percent of the area, and stands of medium stocking occupy the remaining half. In sampling the area, use is made of 20 plots of one-fifth acre each, of which 5 are in dense timber, 5 in open timber, and 10 in timber of medium density. The distribution of the plot volumes is shown in table 35.

The total volume of all 20 plots is 50 M + 60 M + 10 M = 120 M board feet. The estimated volume for the entire area, therefore, totals 1,200,000 board feet and averages 30,000 board feet per acre or 6,000 board feet per plot.

The steps in computing the standard error of this proportionate sampling are as follows:

(1) Add all plot volumes within each group. The group totals for good, medium, and poor stocking, respectively, are 50M, 60M, and 10M board feet (table 35).

(2) Divide each group total obtained in step 1 by the corresponding number of plots, to determine average plot volume for each group. The averages are 10M, 6M, and 2M board feet (table 35).

(3) Calculate the differences between individual plot volumes and the mean volumes for the corresponding density groups. For example, the difference between the volume of plot 1 in the first group and the mean volume for the group is 12M - 10M, or 2M, board feet.

Table 35.--Volume per plot, by density of stand, on a 40-acre tract of northern white pine

Sample plot (number)	Volume per plot, by density of stand		
	Good	Medium	Poor
	M board feet	M board feet	M board feet
1	12	4	1
2	9	5	3
3	10	7	3
4	9	7	2
5	10	8	1
6		5	
7		6	
8		6	
9		7	
10		5	
Total....	50	60	10
Average..	10	6	2

(4) Square all differences calculated in step 3, and add the squares separately for each density group. For the three groups, respectively, the sums of squares are 6, 14, and 4.

(5) Divide each sum of squares obtained in step 4 by the corresponding number of plots less 1. The three divisors are 4, 9, and 4, and the corresponding quotients are 1.500, 1.556, and 1.000. These quotients are the three group variances.

(6) Multiply each group variance obtained in step 5 by the corresponding number of plots (this is the weighting process), and add the products, thus:
$1.500 \times 5 + 1.556 \times 10 + 1.000 \times 5 = 28.06.$

(7) Extract the square root of the result obtained in step 6. The square root of 28.06 is 5.3.

(8) Divide the value obtained in step 7 by the total number of samples taken in all groups, to determine the standard error. The standard error is $\frac{5.3}{20} \times 1{,}000 = 265$ board feet per plot. It corresponds to about 4.4 percent of the general mean.

Calculating the Reliability of Random Sampling

When no effort is made to divide the population into a number of homogeneous blocks and sample each block separately, the sampling is more or less haphazard and its accuracy is somewhat lower. The entire population is regarded as a single group and the samples are taken without restriction anywhere within the area. Under this method it is possible that some strata of the population will be sampled more heavily than others and some will be missed completely. Many cruises of large areas fall in this category.

Under these conditions of sampling, the standard error of the mean depends not only on the variance within different strata of the population but also on the variance between strata. It depends, in other words, on the dispersion of the individual volumes from the mean of the population.

The "total sum of squares" is obtained by--

(1) taking the difference between each individual sample and the general mean of the population computed on the basis of all plots;

(2) squaring the differences; and

(3) adding all the squared differences.

The standard deviation of all samples is then calculated by--

(4) dividing the total sum of squares by the number of samples used less 1, and

(5) extracting the square root of this result.

The standard error is determined by--

(6) dividing the standard deviation obtained in step 5 by the square root of the total number of samples taken on the entire area.

This procedure is the same described in the section headed "Rudiments of Sampling in Timber Cruising."

Intensity of Sampling

Intensity of sampling is a matter of great importance. In planning his cruise, the timber estimator almost invariably wants to know how many samples he should take, or what percentage of the area his samples should total. Even the most experienced cruisers often feel quite uncertain in deciding this question.

The number of samples needed is determined from the following general formula: 6/

$$n = \frac{Nt^2c^2}{Na^2 + t^2c^2}, \text{ where}$$

N is the total number of sampling units in the population, or the total acreage divided by the area of one sample plot,

a is the limit of error of the mean divided by 100,

t is the multiple of the standard error for the limit of error,

c is the ratio of the standard deviation to the population mean, and

n is the required number of samples.

6/ Based on limited population.

As was already mentioned, 3 times the standard error is the usual standard of accuracy of sampling. The chance that this value will be exceeded is only 1 in 370. Unless a lower standard of accuracy is desired, the factor "t" in this equation is 3, and $t^2 = 9$.

The factor "c" is a measure of the relative variation of individual samples of the population, known as the coefficient of variation and previously explained. It is obtained by dividing the standard deviation of the sample plots by the population mean. For example, in the case of the spruce pulpwood stand the ratio between the standard deviation, 2.445, and the general mean, 4, is 0.611. The square of this value, the factor c^2 in the equation, is 0.373, or approximately three-eighths.

If the factor of c^2 is known exactly, then the number of samples needed can be very accurately computed from the formula. When a cruiser starts out on a new tract he has no such exact information. He must either depend on his previous experience with similar tracts or estimate the value of c^2. Table 36 presents approximate values of c^2 for different timber conditions. This table is based on many surveys of large areas. It will be found most helpful to many cruisers as a rough guide.

The use of table 36 requires a knowledge of such general stand characteristics as degree of stocking and the type's yield capacity under normal or good conditions as to stocking and merchantability, and of the probable relative variation in volume. Most cruisers are sufficiently familiar with the general conditions of the timber they intend to sample. Douglas fir, for example, is well known to have a high yield capacity. Northern white pine and the northern hardwoods in the Lake States, also, are high yielders. Lodgepole pine, and balsam fir in the Lake States, are both of low yield capacity. Mature northern hardwoods, as a rule, are uniform in yield capacity even where stocking is poor, but most cut-over stands vary widely in volume from plot to plot.

The following examples will make clear the application of table 36 and the use of the formula for determining the required number of samples.

Table 36.--Approximate values of "c^2" for different timber conditions

Type of stand	Degree of stocking	Yield capacity under normal stocking conditions	Relative variation within stocking groups	Value of c^2
Merchantable Saw-timber stand containing at least 2,000 board feet per acre Cordwood stands containing at least 3 cords per acre	Good	High	High	3/5
			Low	1/10
		Low	High	2/5
			Low	1/4
	Medium	High	High	2/3
			Low	1/5
		Low	High	1/2
			Low	1/3
	Poor	High	High	3/4
			Low	1/3
		Low	High	2/3
			Low	1/2
Unmerchantable Saw-timber stand containing less than 2,000 board feet per acre Cordwood stands containing less than 3 cords per acre	Good	High	High	1½
			Low	1/3
		Low	High	1
			Low	3/4
	Medium	High	High	2
			Low	2/3
		Low	High	1½
			Low	1
	Poor	High	High	3
			Low	1
		Low	High	2
			Low	1½
Mixture of merchantable and unmerchantable saw-timber or cordwood stands	Good	High	High	2
			Low	2/3
		Low	High	1
			Low	3/4
	Medium	High	High	4
			Low	1
		Low	High	2
			Low	1
	Poor	High	High	5
			Low	2
		Low	High	3
			Low	2

Example 1

Mature merchantable northern hardwoods of medium stocking. Area, 40 acres. Plot size, one-quarter acre. The yield capacity of this type is high and its relative variation in volume on any given area is low. The required accuracy of the mean is 20 percent.

$N = 40 \times 4 = 160;$

$a = \frac{20}{100} = 0.2;\ a^2 = 0.2 \times 0.2 = 0.04;$

$t = 3;\ t^2 = 9;$

$c^2 = 1/5;\ Na^2 = 160 \times 0.04 = 6.4;$

$t^2c^2 = \frac{9}{5} = 1.8;\ Nt^2c^2 = 160 \times 1.8 = 288;$

$Na^2 - t^2c^2 = 6.4 + 1.8 = 8.2;$

$n = \frac{288}{8.2} = 35.$

About 35 plots, therefore, are needed for the cruise. This means a $\frac{35}{160} \times 100$ or about 22 percent cruise of the forty.

Example 2

Mature Douglas fir on the Pacific Coast. Area, 2,000 acres. Plot size, one-fifth acre. The yield capacity of the type is high, the general degree of stocking is good, and the relative variation in volume is low. The required accuracy is 3 percent.

$N = 2{,}000 \times 5 = 10{,}000;$

$a = \frac{3}{100} = 0.03;\ a^2 = 0.0009;$

$Na^2 = 10{,}000 \times 0.0009 = 9;$

$t = 3;\ t^2 = 9;\ c^2 = \frac{1}{10};$

$t^2c^2 = \frac{9}{10} = 0.9;\ Na^2 + t^2c^2 = 9 + 0.9 = 9.9;$

$Nt^2c^2 = 10{,}000 \times 0.9 = 9{,}000;$

$n = \frac{9{,}000}{9.9} = 909.$

The required number of plots is 909, and the required intensity of cruise is $\frac{909}{10{,}000} \times 100$, or about 9 percent.

Example 3

A pulpwood stand in Canada. Area, 1,000 acres. Plot size, one-quarter acre. The yield capacity is high, the degree of stocking is good, and the relative variation in volume is low. The required accuracy is 10 percent.

$$Na^2 = 1{,}000 \times 4 \times 0.01 = 40;$$

$$t^2c^2 = 9 \times 0.1 = 0.9;$$

$$Na^2 + t^2c^2 = 40 + 0.9 = 40.9;$$

$$Nt^2c^2 = 4{,}000 \times 0.9 = 3{,}600;$$

$$n = \frac{3{,}600}{40.9} = 88.$$

The required number of plots is 88, and the required intensity of cruise is 2.2 percent.

Example 4

A cut-over area in the Lake States with aspen predominating. Area, 1 township. Plot size, one-fifth acre. The yield capacity is low and the stocking is poor. The relative variation in volume is rather high. Both merchantable and unmerchantable stands are found on the area. The required accuracy is 10 percent.

$$N = 23{,}040 \times 5 = 115{,}200;$$

$$Na^2 = 115{,}200 \times 0.01 = 1{,}152;$$

$$t^2c^2 = 9 \times 3 = 27;$$

$$Na^2 + t^2c^2 = 1{,}152 + 27 = 1{,}179;$$

$$Nt^2c^2 = 115{,}200 \times 27 = 3{,}110{,}400;$$

$$n = \frac{3{,}110{,}400}{1{,}179} = 2{,}638.$$

The required number of plots is 2,638.

On the assumption that most cruisers will be satisfied with odds of 22 to 1 against the errors of sampling exceeding $\pm$ 2 times the standard error ($t = 2$), and that they will ordinarily use quarter-acre sample plots ($N = 4 \times$ area), the formula for required percentage of cruise can be reduced to the form--

$$p = \frac{100c^2}{Aa^2 + c^2},$$

in which "c" and "a" are the same factors as indicated before, "A" is the area of the tract to be cruised in acres, and "p" is the required percentage of cruise. Thus, if $c^2 = 1$, $a^2 = 0.01$ (10-percent accuracy), and the area is 900 acres, it will be necessary to run a 10-percent cruise, for

$$p = \frac{100 \times 1}{900 \times 0.01 + 1} = 10.$$

For convenience, table 37 presents values of p for different accuracies, areas, and values of c^2.

READING REFERENCES

Those interested in learning more about the science of statistics and statistical procedure than is presented here will find these comparatively nontechnical references very instructive:

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(2) Snedecor, George W.
1938. Statistical Methods Applied to Experiments in Agriculture and Biology. 388 pp., illus. Ames, Iowa.
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(3) Mills, Frederick Cecil
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Table 37.--Cruise intensity 1/ needed for different accuracies, by area and value of "c^2"

2-PERCENT ACCURACY

Value of c^2	Intensity of cruise needed on area of-- 40 acres	160 acres	640 acres	5,000 acres	20,000 acres
	Percent	Percent	Percent	Percent	Percent
1/10	100	61	28	5	1
1/5	"	100	44	9	2
1/4	"	"	49	11	3
1/3	"	"	57	14	4
2/5	"	"	61	17	5
1/2	"	"	100	20	6
3/5	"	"	"	23	7
2/3	"	"	"	25	8
3/4	"	"	"	27	9
1	"	"	"	33	11
1½	"	"	"	43	16
2	"	"	"	50	20
3	"	"	"	60	27
4	"	"	"	100	33
5	"	"	"	"	38

10-PERCENT ACCURACY

Value of c^2	Intensity of cruise needed on area of-- 40 acres	160 acres	640 acres	5,000 acres	20,000 acres
	Percent	Percent	Percent	Percent	Percent
1/10	20	6			
1/5	33	11	3		
1/4	38	14	4		
1/3	45	17	5		
2/5	50	20	6		
1/2	56	24	7		
3/5	60	27	9		
2/3	100	29	9		
3/4	"	32	10		
1	"	38	14	2	
1½	"	48	19	3	1
2	"	56	24	4	1
3	"	100	32	6	1
4	"	"	38	7	2
5	"	"	44	9	2

5-PERCENT ACCURACY

Value of c^2	40 acres	160 acres	640 acres	5,000 acres	20,000 acres
1/10	50	20	6		
1/5	100	33	11	2	
1/4	"	38	14	2	
1/3	"	45	17	3	
2/5	"	50	20	3	1
1/2	"	56	24	4	1
3/5	"	60	27	5	1
2/3	"	100	29	5	1
3/4	"	"	32	6	1
1	"	"	38	7	2
1½	"	"	48	11	3
2	"	"	56	14	4
3	"	"	100	19	6
4	"	"	"	24	7
5	"	"	"	29	9

20-PERCENT ACCURACY

Value of c^2	40 acres	160 acres	640 acres	5,000 acres	20,000 acres
1/10	6				
1/5	11				
1/4	14				
1/3	17	5			
2/5	20	6			
1/2	24	7			
3/5	27	9			
2/3	29	9			
3/4	32	10	3		
1	38	14	4		
1½	48	19	6		
2	56	24	7	1	
3		32	10	1	
4		38	14	2	
5		44	16	2	1

1/ Computed to the nearest percent.

APPENDIX

FORM-CLASS AND TAPER AVERAGES FOR REPRESENTATIVE TIMBER SPECIES

Averages of form class and taper, by d.b.h., for certain timber species have been calculated on the basis of measurements of more than 100,000 sample trees in different parts of the United States, chiefly in connection with the Nation-wide Forest Survey. These averages are shown in table 38.

The top diameter of the first 16-foot log can be determined by multiplying d.b.h. by form class. If a tree is 30 inches in d.b.h. and has a form class of 0.80, the top diameter inside bark of its first 16-foot log is 30 x 0.80 = 24.0 inches. For convenience, top diameters of the butt log in trees of various diameters and form classes are presented in table 39. The top diameters of the second, third, and additional logs can be determined by subtracting the indicated taper.

Table 38 .—Some form-class and taper averages for representative timber species

Species and Condition	Locality	Diameter group	Form class	Taper per 16-foot log 2nd	3rd	4th	5th	6th	7th	Sample trees
		Inches		Inches	Inches	Inches	Inches	Inches	Inches	Number
Loblolly pine										
Old growth	South Carolina	18 - 22	0.82	1.5	1.8	2.0				200
	do	14 - 22	.82	1.5	1.9	2.1				150
Second growth										
Forest grown	do	10 - 14	.78	1.5	1.8					150
	do	10 - 18	.78	1.6	1.9	2.5				180
Old field	do	10 - 18	.77	1.8	2.5					160
Slash pine old growth	Florida, Georgia, South Carolina, and Alabama	14 - 24	.82	1.3	1.6	2.0	3.0			1,500
Longleaf pine old growth	East Texas	12 - 18	.85	1.3	1.6	2.0				600
	do	20 - 28	.85	1.5	1.8	2.2	2.8			800
Shortleaf pine old growth	Mississippi, Arkansas, Louisiana, and southeast Texas	14 - 24	.84	1.3	1.6	2.0	3.0			2,000
Ponderosa pine old growth	Montana	16 - 20	.78	1.6	2.0	2.2				
	do	22 - 26	.81	1.4	1.8	2.4	3.0			
	do	28 - 32	.81	1.4	2.0	2.6	3.4	4.0		1,400
	Klamath County, Oreg.	16 - 20	.79	1.1	1.4	1.7	2.1			
	do	22 - 28	.82	1.3	1.6	2.1	2.7	3.5		
	do	28 - 32	.82	1.1	1.6	2.3	3.4	4.7		
	do	34 - 38	.83	1.0	1.5	2.2	3.0	3.8	4.7	95
	Jefferson County, Oreg.	14 - 20	.77	2.2	2.6	3.0				
	do	22 - 26	.80	2.8	3.5	4.2	5.0			
	Deschutes County, Oreg.	14 - 20	.80	1.7	2.2	2.8				
	do	22 - 26	.80	1.2	2.3	3.1	3.7			
	do	28 - 32	.80	1.5	2.6	3.6	4.3			250
Red spruce old growth	Appalachian Mountains	12 - 16	.85	1.8	2.0					
	do	18 - 22	.85	1.8	2.0	2.2				
	do	24 - 28	.84	1.9	2.5	2.8	3.2			450

Table 38 .--Some form-class and taper averages for representative timber species--Continued

Species and condition	Locality	Diameter group	Form class	Taper per 16-foot log						Sample trees
				2nd	3rd	4th	5th	6th	7th	
		Inches		Inches	Inches	Inches	Inches	Inches	Inches	Number
Hemlock old growth	Michigan and Wisconsin	12 - 16	0.77	1.8	2.0					
	do	16 - 22	.77	1.8	2.2					
	do	24 - 28	.77	2.4	2.7	3.2				
	do	30 - 34	.77	2.5	3.0	5.5				660
Beech old growth	New England	12 - 16	.63	1.5						200
	do	18 - 22	.82	1.8	3.1					150
	do	24 - 28	.81	2.1	3.6					200
	Michigan	12 - 16	.84	1.6						
	do	18 - 22	.83	1.6	2.0					
	do	24 - 28	.82	1.7	2.4					
	do	30 - 34	.82	2.0	2.5					400
Sugar maple old growth	New England	12 - 16	.77	1.4	1.8					200
	do	18 - 26	.78	2.1	2.3					350
	do	28 - 32	.78	2.3	2.5					150
	Michigan and Wisconsin	12 - 16	.78	1.6						
	do	18 - 22	.78	1.6	1.8					
	do	24 - 28	.78	1.7	2.0					
	do	30 - 54	.78	2.0	2.5					1,070
llow birch old growth	New England	12 - 20	.78	2.0	2.4					200
	do	22 - 30	.78	3.1	3.5					400
	Michigan and Wisconsin	12 - 16	.78	1.7						
	do	18 - 22	.78	1.6	1.8					
	do	24 - 28	.78	2.0	2.3					
	do	30 - 34	.78	2.2	2.9					500
sswood old growth	do	12 - 16	.78	1.6						
	do	18 - 22	.77	1.8	2.0					
	do	24 - 28	.77	2.3	2.6					
	do	30 - 34	.77	2.5	2.9					460
lm old growth	do	12 - 16	.79	1.6						
	do	18 - 22	.80	1.7	2.0					
	do	24 - 28	.80	1.8	2.5					
	do	30 - 34	.79	2.0	2.8					490

Table 38 .—Some form-class and taper averages for representative timber species—Continued

Species and condition	Locality	Diameter group	Form class	Taper per 16-foot log						Sample trees
				2nd	3rd	4th	5th	6th	7th	
		Inches		Inches	Inches	Inches	Inches	Inches	Inches	Number
Red oak old growth	Appalachian Mountains	12 - 16	0.79	1.5						
	do	18 - 22	.79	1.7	2.0					
	do	24 - 28	.79	2.0	2.2	2.4				300
	Texas, Georgia, Alabama, Mississippi, and Louisiana river bottoms	20 - 30	.77	1.7	2.0	2.3				2,000
Red and white oak old growth	Michigan and Wisconsin	12 - 16	.77	2.0						
	do	18 - 22	.77	1.9	2.1					
	do	24 - 28	.77	2.0	2.8					
	do	30 - 34	.77	2.3	3.1					700
Yellow poplar Old growth	South Carolina	30 - 40	.84	1.4	2.0	2.6	3.0			150
	do	18 - 28	.84	1.3	1.8	2.4	2.8			200
Second growth	North and South Carolina	14 - 18	.78	1.7	2.0	2.2				
	do	20 - 24	.78	1.8	2.3	2.5				400
Red gum old growth	South Carolina	14 - 20	.78	1.5	1.8	2.0				250
	do	22 - 28	.79	1.6	1.8	2.1				300
	do	30 - 38	.79	1.7	1.9	2.2	2.6			150
	Mississippi delta and river bottoms	20 - 30	.78	1.8	2.0	2.2				1,500
White ash old growth	New England	14 - 22	.76	2.3	2.8	3.3				200
	do	22 - 30	.77	3.3	3.6	3.8				300
Paper birch old growth	do	10 - 14	.82	1.6						250
	do	16 - 20	.80	2.5	3.1					150

Table 39.--Top diameter of butt log in trees of various diameters and form classes

D.b.h. (inches)	Top diameter inside bark of butt log (inches), by form class											
	0.63	0.64	0.65	0.66	0.67	0.68	0.69	0.70	0.71	0.72	0.73	0.74
12	7.6	7.7	7.8	7.9	8.0	8.2	8.3	8.4	8.5	8.6	8.8	8.9
14	8.8	9.0	9.1	9.2	9.4	9.5	9.7	9.8	9.9	10.1	10.2	10.4
16	10.1	10.2	10.4	10.6	10.7	10.9	11.0	11.2	11.4	11.5	11.7	11.8
18	11.3	11.5	11.7	11.9	12.1	12.2	12.4	12.6	12.8	13.0	13.1	13.3
20	12.6	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.2	14.4	14.6	14.8
22	13.9	14.1	14.3	14.5	14.7	15.0	15.2	15.4	15.6	15.8	16.1	16.3
24	15.1	15.4	15.6	15.8	16.1	16.3	16.6	16.8	17.0	17.3	17.5	17.8
26	16.4	16.6	16.9	17.2	17.4	17.7	17.9	18.2	18.5	18.7	19.0	19.2
28	17.6	17.9	18.2	18.5	18.8	19.0	19.3	19.6	19.9	20.2	20.4	20.7
30	18.9	19.2	19.5	19.8	20.1	20.4	20.7	21.0	21.3	21.6	21.9	22.2
32	20.2	20.5	20.8	21.1	21.4	21.8	22.1	22.4	22.7	23.0	23.4	23.7
34	21.4	21.8	22.1	22.4	22.8	23.1	23.5	23.8	24.1	24.5	24.8	25.2
36	22.7	23.0	23.4	23.8	24.1	24.5	24.8	25.2	25.6	25.9	26.3	26.6
38	23.9	24.3	24.7	25.1	25.5	25.8	26.2	26.6	27.0	27.4	27.7	28.1
40	25.2	25.6	26.0	26.4	26.8	27.2	27.6	28.0	28.4	28.8	29.2	29.6

Table 39.—Top diameter of butt log in trees of various diameters and form classes — Continued

D.b.h. (inches)	Top diameter inside bark of butt log (inches), by form class										
	0.75	0.76	0.77	0.78	0.79	0.80	0.81	0.82	0.83	0.84	0.85
12	9.0	9.1	9.2	9.4	9.5	9.6	9.7	9.8	10.0	10.1	10.2
14	10.5	10.6	10.8	10.9	11.1	11.2	11.3	11.5	11.6	11.8	11.9
16	12.0	12.2	12.3	12.5	12.6	12.8	13.0	13.1	13.3	13.4	13.6
18	13.5	13.7	13.9	14.0	14.2	14.4	14.6	14.8	14.9	15.1	15.3
20	15.0	15.2	15.4	15.6	15.8	16.0	16.2	16.4	16.6	16.8	17.0
22	16.5	16.7	16.9	17.2	17.4	17.6	17.8	18.0	18.3	18.5	18.7
24	18.0	18.2	18.5	18.7	19.0	19.2	19.4	19.7	19.9	20.2	20.4
26	19.5	19.8	20.0	20.3	20.5	20.8	21.1	21.3	21.6	21.8	22.1
28	21.0	21.3	21.6	21.8	22.1	22.4	22.7	23.0	23.2	23.5	23.8
30	22.5	22.8	23.1	23.4	23.7	24.0	24.3	24.6	24.9	25.2	25.5
32	24.0	24.3	24.6	25.0	25.3	25.6	25.9	26.2	26.6	26.9	27.2
34	25.5	25.8	26.2	26.5	26.9	27.2	27.5	27.9	28.2	28.6	28.9
36	27.0	27.4	27.7	28.1	28.4	28.8	29.2	29.5	29.9	30.2	30.6
38	28.5	28.9	29.3	29.6	30.0	30.4	30.8	31.2	31.5	31.9	32.3
40	30.0	30.4	30.8	31.2	31.6	32.0	32.4	32.8	33.2	33.6	34.0

TAPER FACTORS

As is explained in chapter 9, the form diameter of a tree, or Do, may be expressed by the ratio $\frac{DF}{T}$, in which D is the tree's diameter outside bark at breast height, F is its form class, and T is a factor denoting the rate of taper of the merchantable stem above the standard (16-foot) butt log. DF, obviously, is the top diameter inside bark of the first 16-foot log.

The taper factor, T, which varies with d.b.h. and log height, is determined by means of specially prepared tables, presented here as tables 40 and 41. To use these tables the cruiser should know the taper above the first log, or the so-called taper index values t_2, t_3, and t_4. For 2-log trees, the taper index t_2 (in inches) is determined by subtracting from the taper between the tops of the first and second logs one-tenth of the diameter at breast height. For 3-log trees, in addition to t_2 the t_3 index is determined, by subtracting one-tenth of the d.b.h. from the taper between the tops of the second and third logs. For 4- to 6-log trees, in addition to t_2 and t_3 the taper index t_4 is determined, by subtracting one-tenth of the d.b.h. from the taper between the tops of the third and fourth logs. On the basis of the taper indices the values of T_2, T_3, and T_4 are obtained from tables 40 and 41. The algebraic sum of the T_2, T_3, and T_4 values is the required taper factor, T. Thus, for 2-log trees $T = T_2$, for 3-log trees $T = T_2 + T_3$, and for 4-log or taller trees $T = T_2 + T_3 + T_4$. In general, negative values of the taper indices indicate slow taper, and positive values indicate rapid taper.

The following examples illustrate the method of using taper factors to calculate timber volume.

Example 1

The tree is a 24-inch sugar maple. The cruiser finds that only two 16-foot sawlogs can be utilized from this tree. He finds that the form class is 0.78 and the taper between the tops of the first and second logs is 1.8 inches. He determines that the taper index t_2 is $1.8 - \frac{24}{10} = -0.6$. Referring to table 40, and interpolating, he reads the value of the taper factor T_2 corresponding to a d.b.h. of 24 inches and a t_2 of -0.6 as 0.804. He now computes the form diameter as $\frac{24 \times 0.78}{0.804} = 23.3$ inches. Referring to table 10, he obtains the board-foot volume of this tree, without scaling the individual logs, as 421 board feet, Scribner scale.

This result can be checked by the direct process. The butt log of this tree has a top diameter of $24 \times 0.78 = 18.7$ inches, and the second log has a top diameter of $18.7 - 1.8 = 16.9$ inches. The combined scale of these logs, as determined from the Scribner log rule, table 46, is $235 + 188 = 423$ board feet.

Table 40.--Taper factors for second log, by d.b.h. and taper index

D.b.h.	Taper factor T_2, by taper index t_2									
(inches)	-2.0 inches	-1.5 inches	-1.0 inches	-0.5 inches	0 inches	+0.5 inches	+1.0 inches	+1.5 inches	+2.0 inches	+2.5 inches
10		0.762	0.774	0.787	0.807	0.832	0.853	0.873	0.890	
11		.764	.775	.789	.808	.831	.851	.871	.888	
12		.766	.777	.790	.809	.831	.850	.869	.886	
13		.768	.779	.792	.809	.830	.848	.867	.884	
14		.770	.780	.793	.810	.830	.846	.865	.882	
15		.772	.782	.794	.811	.829	.845	.863	.880	
16		.774	.783	.796	.811	.829	.844	.861	.878	
17		.776	.785	.797	.812	.828	.842	.859	.876	
18		.778	.786	.798	.813	.828	.841	.857	.874	
19		.779	.788	.799	.814	.827	.840	.855	.872	
20	0.774	.781	.789	.801	.814	.827	.838	.854	.870	
21	.775	.783	.791	.802	.815	.826	.837	.852	.869	
22	.776	.784	.792	.803	.815	.826	.836	.851	.867	
23	.778	.785	.793	.804	.816	.825	.835	.849	.866	
24	.779	.787	.795	.805	.816	.825	.834	.848	.864	
25	.780	.788	.796	.807	.817	.825	.833	.847	.863	
26	.781	.789	.797	.808	.818	.824	.832	.846	.862	
27	.782	.790	.798	.809	.818	.824	.831	.845	.861	
28	.783	.791	.800	.810	.819	.824	.831	.844	.860	
29	.783	.792	.801	.811	.819	.824	.830	.843	.859	
30	.784	.792	.802	.812	.820	.823	.830	.842	.858	
31	.785	.793	.803	.813	.820	.823	.829	.842	.858	
32	.785	.794	.804	.814	.820	.823	.829	.841	.857	
33	.786	.795	.804	.815	.821	.823	.829	.841	.857	

Table 41.--Taper factors for third log and for fourth and additional logs, by taper index

Taper index t_3	Taper factor T_3	Taper index t_4	Taper factor T_4
-2.0	-0.017	-2.4	-0.019
-1.8	- .017	-2.2	- .018
-1.7	- .017	-2.1	- .018
-1.6	- .016	-2.0	- .017
-1.5	- .016	-1.9	- .017
-1.4	- .015	-1.8	- .016
-1.3	- .015	-1.7	- .016
-1.2	- .014	-1.6	- .015
-1.1	- .013	-1.5	- .015
-1.0	- .012	-1.4	- .014
- .9	- .010	-1.3	- .014
- .8	- .009	-1.2	- .013
- .7	- .007	-1.1	- .012
- .6	- .005	-1.0	- .012
- .5	- .002	- .9	- .011
- .4	0	- .8	- .010
- .3	+ .004	- .7	- .010
- .2	+ .008	- .6	- .009
- .1	+ .010	- .5	- .008
0	+ .013	- .4	- .007
+ .1	+ .015	- .3	- .006
+ .2	+ .016	- .2	- .006
+ .3	+ .018	- .1	- .005
+ .4	+ .020	- .0	- .004
+ .5	+ .022	+ .1	- .001
+ .6	+ .024	+ .2	+ .001
+ .7	+ .025	+ .3	+ .004
+ .8	+ .027	+ .4	+ .006
+ .9	+ .028	+ .5	+ .008
+1.0	+ .030	+ .6	+ .009
+1.1	+ .032	+ .7	+ .010
+1.2	+ .033	+ .8	+ .011
+1.3	+ .035	+ .9	+ .011
+1.4	+ .037	+1.0	+ .012
+1.5	+ .038	+1.1	+ .013
+1.6	+ .040	+1.2	+ .013
+1.7	+ .042	+1.3	+ .014
+1.8	+ .043	+1.4	+ .015
+1.9	+ .045	+1.5	+ .016
+2.0	+ .047	+1.6	+ .016
+2.1	+ .048	+1.7	+ .017
+2.2	+ .050	+1.8	+ .018
+2.3	+ .052	+1.9	+ .018
+2.4	+ .053	+2.0	+ .019
+2.5	+ .055	+2.1	+ .019
+2.6	+ .057	+2.2	+ .020
+2.7	+ .058	+2.3	+ .021
+2.8	+ .059	+2.4	+ .022
+2.9	+ .061	+2.5	+ .023
+3.0	+ .063		
+3.1	+ .064		
+3.2	+ .065		
+3.3	+ .065		

Example 2

A 22-inch elm has a merchantable height of three 16-foot logs. Its estimated form class is 0.75. The taper between the first and second logs is 1.8 inches, and the taper between the second and third logs is 2.1 inches. The taper index t_2 is $1.8 - \frac{22}{10} = -0.4$, and the taper index t_3 is $2.1 - \frac{22}{10} = -0.1$. The corresponding components of the taper factor, obtained from tables 40 (by interpolation) and 41, are $T_2 = +0.805$ and $T_3 = +0.010$. The final taper factor, T, the sum of T_2 and T_3, is $0.805 + 0.010 = 0.815$. The form diameter is $\frac{22 \times 0.75}{0.815} = 20.2$ inches, and the volume, as obtained from table 10, is 416 board feet, Scribner scale. Calculated by the direct process, the scale is $178 + 137 + 96 = 411$ board feet.

Example 3

The tree is a red gum 26.0 inches in d.b.h. and 4 logs in height. The form class is 0.80, and the tapers of the second, third, and fourth logs, respectively, are 1.3, 1.8, and 1.0 inch. The values of t_2, t_3, and t_4 are quickly obtained as -1.3, -0.8, and -1.6 inches. From tables 40 and 41 the corresponding values of T_2, T_3, and T_4 are read (by simple interpolation when necessary) as + 0.792, -0.009, and -0.015. The sum of these values is 0.768. Having this information, the cruiser determines the form diameter as $\frac{26 \times 0.80}{0.768} = 27.1$ inches. The volume corresponding to this form diameter, according to table 10, is 943 board feet. The actual scale of this tree is 944 board feet.

In applying this method, taper factors need not be determined for every tree. They can be determined on the basis of the average form class and average taper (in inches) of all trees in a given d.b.h. and log-height class. When the average taper factors are converted into form diameters, the latter can be used for the construction of a volume table, as outlined in chapter 9 under "Form-Diameter Method." Through use of taper factors, scaling trees in Scribner board feet becomes unnecessary.

Cruisers who have trained themselves in estimating the form class and taper of standing trees may find the short-cut method described here very useful in preparing Scribner volume tables for any species. Although the method gives best results when actual measurements of taper of individual trees are available, it is more suitable for use in connection with ocular estimates of taper. Obviously, only skillful cruisers should use it, since its accuracy depends primarily on how closely the taper of standing trees is estimated.

FREE-HAND DRAWING OF CURVES

Very frequently, a timber cruiser needs to draw curves showing the relation between two measured quantities, such as merchantable height and d.b.h. or volume and d.b.h. Practically all methods of preparing volume tables require fitting curves to measurements.

Original measurements when plotted on cross-section paper often show considerable irregularity in trend, especially when points are plotted on the basis of few observations. As the number of observations is increased the trend becomes more definite, up to a certain point. When all points are plotted on cross-section paper, the curving process is merely that of averaging graphically the values of the plotted measurements. As a general rule, averages based on large numbers of measurements give smooth curves. Smoothing of a curve, therefore, results in approximation of the final curve that would result if more observations were recorded.

It should be remembered that a "dependent" variable is always plotted over an "independent" variable, e.g., volume is plotted over diameter or height and height is plotted over age, not vice versa. The scale of the graph, especially the vertical scale, should be chosen carefully so as to make the reading of the curve easy.

In drawing freehand curves, the following rules should be remembered: (1) The curve should fit the plotted points; and (2) the shape of the curve should be logical.

Let us turn to figure 8. In this graph 10 merchantable heights (to a top diameter not less than 6 inches) of yellow birch are plotted over the corresponding breast-height diameters. For illustrations three curves, A, B, and C, are drawn through these points. Which one of these best fits the points and is also logical?

We read the heights from the three curves and tabulate them together with the differences, positive and negative, between the heights read from the curve and the observed heights (table 42).

Since each point represents only one tree, each tabulated value has the same weight. The differences between the curve values and the corresponding observed values, presented in the last six columns of the table, are very significant. Curve A, which is a straight line, is clearly out of balance, aside from being illogical. The sum of negative deviations (27 feet) is much higher than the sum of positive deviations (10 feet). The sum of both positive and negative deviations, 37 feet, is very high. Obviously, curve A does not fit the data at all and should be rejected. Curve B, also a straight line, is a slight improvement on Curve A, but still is not a line of good fit. Although the positive and negative deviations of the curve from the observed heights nearly balance each other (15 feet against 16 feet), the total positive and negative deviation is still too high. As in the case of curve A, also, the trend of curve B is illogical; merchantable heights do not increase with d.b.h. at a constant rate.

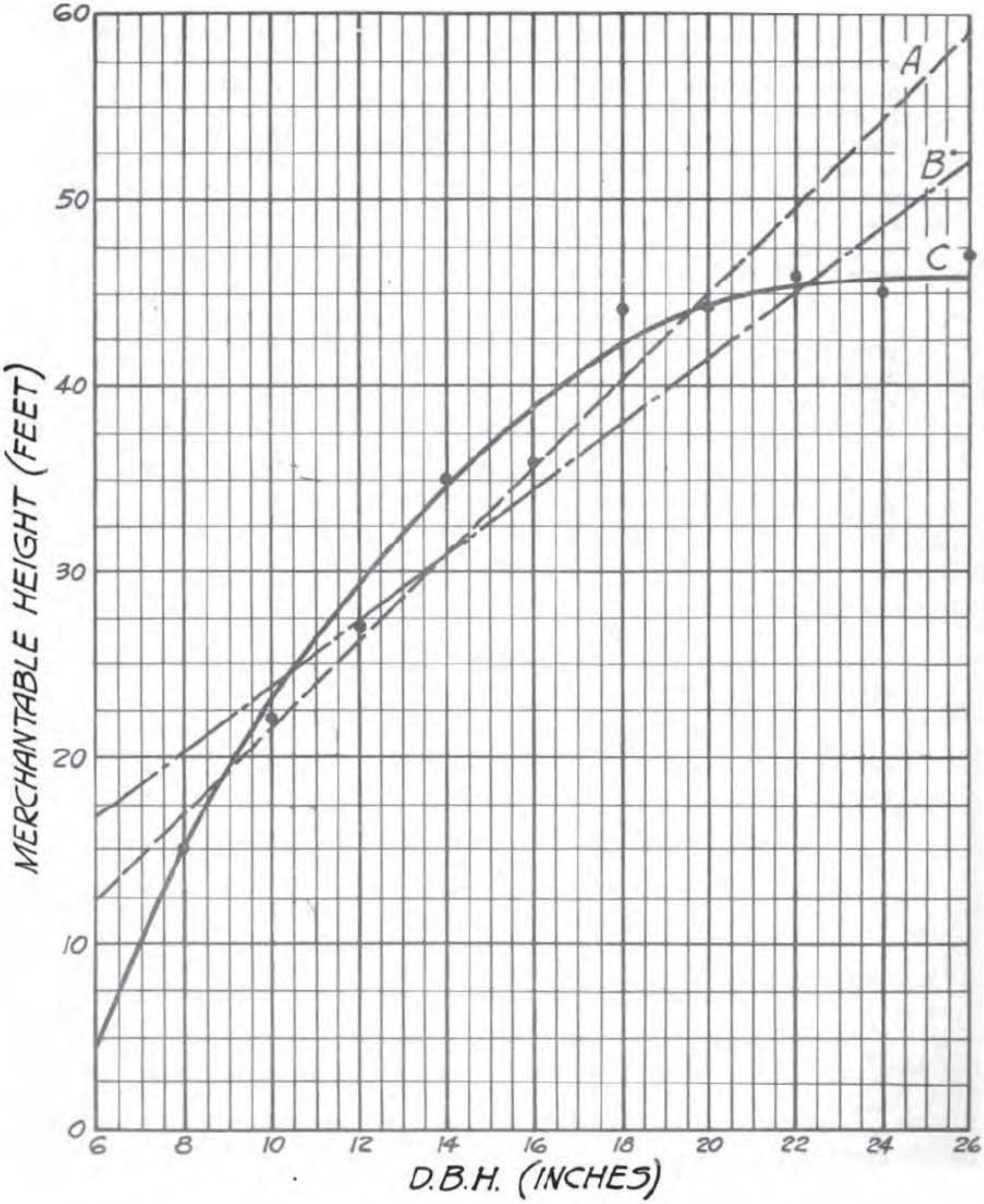

FIGURE 8 - FITTING A CURVE

Table 42. --Fit of three free-hand curves shown in figure 8 to basic data

D.b.h. (inches)	Observed merchantable height	Merchantable height as shown by --			Differences					
		Curve A	Curve B	Curve C	Curve A		Curve B		Curve C	
	Feet	Feet	Feet	Feet	Feet		Feet		Feet	
8	15	17	20	15		- 2		- 5		
10	22	22	24	22				- 2		
12	27	26	27	29	+ 1					- 2
14	35	31	31	34	+ 4		+ 4		+ 1	
16	36	35	34	38	+ 1		+ 2			- 2
18	44	40	38	42	+ 4		+ 6		+ 2	
20	44	45	42	44		- 1	+ 2			
22	46	49	45	45		- 3	+ 1		+ 1	
24	45	54	49	46		- 9		- 4		- 1
26	47	59	52	46		-12		- 5	+ 1	
Total positive and total negative deviation					+10	-27	+15	-16	+ 5	- 5
Total deviation					37		31		10	

Curve C, on the other hand, possesses all the qualities of a well-fitting curve. First of all, it is balanced, since the sums of positive and negative deviations are identical. Second, the total of all positive and negative deviations of the observed heights from the curve, 10 feet, is small, at any rate much smaller than the similar total for either curve A or curve B. In addition to showing the smallest deviations from the points, curve C is in accord with common sense. For example, curve C shows merchantable height increasing rapidly with d.b.h. in the 6- to 12-inch d.b.h. range, less rapidly in the 12- to 18-inch range, and slowly for trees larger than 18 inches in d.b.h. This checks with experience with the species involved. Curve C, therefore, is the one that should be used.

The general rule for simple free-hand curving, therefore, is as follows:

1. Observe the scatter of the plotted points and the general trend they suggest.

2. Draw a tentative curve.

3. Read the deviation of the curve, negative or positive, from each plotted point.

4. If the sum of the positive deviations is not the same as the sum of the negative deviations, adjust the curve so that the two sums become equal.

5. Observe the scatter of the points around the new curve and see if the trend is a logical one.

When averages rather than individual measurements are plotted on cross-section paper, then in balancing curves consideration must be given to the so-called weights of the points, the numbers of observations used in computing them. A point based on 30 trees, for instance, is considered as having a weight of 30 units. If such a point is below the curve by 2 feet (represented by two of the smallest spaces of the cross-section paper), its total deviation from the curve is equivalent to 60 feet (represented by 60 spaces). If a point deviates from the curve by 6 feet instead of 2, but is based on only 10 trees instead of 30, its total deviation is likewise 60 feet. If the second point is above the curve, its total deviation balances that of the first.

BASAL AREA TABLE

Table 43.--Areas of circles (basal areas)

Diameter (full inches)	Area by additional fraction of inch of diameter									
	0.0 inch	0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch	0.6 inch	0.7 inch	0.8 inch	0.9 inch
	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.
1	0.005	0.007	0.008	0.009	0.011	0.012	0.014	0.016	0.018	0.020
2	.022	.024	.026	.029	.031	.034	.037	.040	.043	.046
3	.049	.052	.056	.059	.063	.067	.071	.075	.079	.083
4	.087	.092	.096	.101	.106	.110	.115	.120	.126	.131
5	.136	.142	.147	.153	.159	.165	.171	.177	.183	.190
6	.196	.203	.210	.216	.223	.230	.238	.245	.252	.260
7	.267	.275	.283	.291	.299	.307	.315	.323	.332	.340
8	.349	.358	.367	.376	.385	.394	.403	.413	.422	.432
9	.442	.452	.462	.472	.482	.492	.503	.513	.524	.535
10	.545	.556	.567	.579	.590	.601	.613	.624	.636	.648
11	.660	.672	.684	.696	.709	.721	.734	.747	.759	.772
12	.785	.799	.812	.825	.839	.852	.866	.880	.894	.908
13	.922	.936	.950	.965	.979	.994	1.009	1.024	1.039	1.054
14	1.069	1.084	1.100	1.115	1.131	1.147	1.163	1.179	1.195	1.211
15	1.227	1.244	1.260	1.277	1.294	1.310	1.327	1.344	1.362	1.379
16	1.396	1.414	1.431	1.449	1.467	1.485	1.503	1.521	1.539	1.558
17	1.576	1.595	1.614	1.632	1.651	1.670	1.689	1.709	1.728	1.748
18	1.767	1.787	1.807	1.827	1.847	1.867	1.887	1.907	1.928	1.948
19	1.969	1.990	2.011	2.032	2.053	2.074	2.095	2.117	2.138	2.160
20	2.182	2.204	2.226	2.248	2.270	2.292	2.315	2.337	2.360	2.382
21	2.405	2.428	2.451	2.474	2.498	2.521	2.545	2.568	2.592	2.616
22	2.640	2.664	2.688	2.712	2.737	2.761	2.786	2.810	2.835	2.860
23	2.885	2.910	2.936	2.961	2.986	3.012	3.038	3.064	3.089	3.115
24	3.142	3.168	3.194	3.221	3.247	3.274	3.301	3.328	3.355	3.382
25	3.409	3.436	3.464	3.491	3.519	3.547	3.574	3.602	3.631	3.659

Table 43.--Areas of circles (basal areas) --Continued

Diameter (full inches)	Area by additional fraction of inch of diameter									
	0.0 inch	0.1 inch	0.2 inch	0.3 inch	0.4 inch	0.5 inch	0.6 inch	0.7 inch	0.8 inch	0.9 inch
	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.	Sq.ft.
26	3.69	3.72	3.74	3.77	3.80	3.83	3.86	3.89	3.92	3.95
27	3.98	4.01	4.04	4.06	4.09	4.12	4.15	4.18	4.22	4.25
28	4.28	4.31	4.34	4.37	4.40	4.43	4.46	4.49	4.52	4.56
29	4.59	4.62	4.65	4.68	4.71	4.75	4.78	4.81	4.84	4.88
30	4.91	4.94	4.97	5.01	5.04	5.07	5.11	5.14	5.17	5.21
31	5.24	5.28	5.31	5.34	5.38	5.41	5.45	5.48	5.52	5.55
32	5.59	5.62	5.66	5.69	5.73	5.76	5.80	5.83	5.87	5.90
33	5.94	5.98	6.01	6.05	6.08	6.12	6.16	6.19	6.23	6.27
34	6.31	6.34	6.38	6.42	6.45	6.49	6.53	6.57	6.61	6.64
35	6.68	6.72	6.76	6.80	6.83	6.87	6.91	6.95	6.99	7.03
36	7.07	7.11	7.15	7.19	7.23	7.27	7.31	7.35	7.39	7.43
37	7.47	7.51	7.55	7.59	7.63	7.67	7.71	7.75	7.79	7.83
38	7.88	7.92	7.96	8.00	8.04	8.08	8.13	8.17	8.21	8.25
39	8.30	8.34	8.38	8.42	8.47	8.51	8.55	8.60	8.64	8.68
40	8.73	8.77	8.81	8.86	8.90	8.95	8.99	9.03	9.08	9.12
41	9.17	9.21	9.26	9.30	9.35	9.39	9.44	9.48	9.53	9.58
42	9.62	9.67	9.71	9.76	9.81	9.85	9.90	9.94	9.99	10.04
43	10.08	10.13	10.18	10.23	10.27	10.32	10.37	10.42	10.46	10.51
44	10.56	10.61	10.66	10.70	10.75	10.80	10.85	10.90	10.95	11.00
45	11.04	11.09	11.14	11.19	11.24	11.29	11.34	11.39	11.44	11.49
46	11.54	11.59	11.64	11.69	11.74	11.79	11.84	11.89	11.95	12.00
47	12.05	12.10	12.15	12.20	12.25	12.31	12.36	12.41	12.46	12.51
48	12.57	12.62	12.67	12.72	12.78	12.83	12.88	12.94	12.99	13.04
49	13.10	13.15	13.20	13.26	13.31	13.36	13.42	13.47	13.53	13.58
50	13.64	13.69	13.74	13.80	13.85	13.91	13.96	14.02	14.08	14.13

LOG RULES

Table 44.--Scribner log rule

Top diameter of log inside bark (inches)	Volume of log by length				
	12 feet	14 feet	16 feet	18 feet	20 feet
	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.
6	12	14	18	22	24
7	18	24	28	32	34
8	24	28	32	40	44
9	30	35	40	45	50
10	40	45	50	55	65
11	50	55	65	70	80
12	59	69	79	88	98
13	73	85	97	109	122
14	86	100	114	129	143
15	107	125	142	160	178
16	119	139	159	178	198
17	139	162	185	208	232
18	160	187	213	240	267
19	180	210	240	270	300
20	210	245	280	315	350
21	228	266	304	342	380
22	251	292	334	376	418
23	283	330	377	424	470
24	303	353	404	454	505
25	344	401	459	516	573
26	375	439	500	562	625
27	411	479	548	616	684
28	436	509	582	654	728
29	457	539	609	685	761
30	493	575	657	739	821
31	532	622	710	799	888
32	552	644	736	828	920
33	588	686	784	882	980
34	600	700	800	900	1,000
35	657	766	876	985	1,095
36	692	807	923	1,038	1,152
37	772	901	1,029	1,158	1,287
38	801	934	1,068	1,201	1,335
39	840	980	1,120	1,260	1,400
40	903	1,053	1,204	1,354	1,505
41	954	1,113	1,272	1,431	1,590
42	1,007	1,175	1,343	1,511	1,679
43	1,046	1,222	1,396	1,571	1,745
44	1,110	1,295	1,480	1,665	1,850
45	1,139	1,329	1,518	1,707	1,898
46	1,190	1,388	1,587	1,785	1,983
47	1,242	1,449	1,656	1,862	2,070
48	1,296	1,512	1,728	1,944	2,160

Table 45.--Scribner Decimal C log rule

Top diameter of log inside bark (inches)	Volume of log (board feet in tens) by length									
	6 feet	8 feet	10 feet	12 feet	14 feet	16 feet[1]	18 feet	20 feet	22 feet	24 feet
6	0.5	0.5	1	1	1	2	2	2	3	3
7	.5	1	1	2	2	3	3	3	4	4
8	1	1	2	2	2	3	3	3	4	4
9	1	2	3	3	3	4	4	4	5	6
10	2	3	3	3	4	6	6	7	8	9
11	2	3	4	4	5	7	8	8	9	10
12	3	4	5	6	7	8	9	10	11	12
13	4	5	6	7	8	10	11	12	13	15
14	4	6	7	9	10	11	13	14	16	17
15	5	7	9	11	12	14	16	18	20	21
16	6	8	10	12	14	16	18	20	22	24
17	7	9	12	14	16	18	21	23	25	28
18	8	11	13	16	19	21	24	27	29	32
19	9	12	15	18	21	24	27	30	33	36
20	11	14	17	21	24	28	31	35	38	42
21	12	15	19	23	27	30	34	38	42	46
22	13	17	21	25	29	33	38	42	46	50
23	14	19	23	28	33	38	42	47	52	57
24	15	21	25	30	35	40	45	50	55	61
25	17	23	29	34	40	46	52	57	63	69
26	19	25	31	37	44	50	56	62	69	75
27	21	27	34	41	48	55	62	68	75	82
28	22	29	36	44	51	58	65	73	80	87
29	23	31	38	46	53	61	68	76	84	91
30	25	33	41	49	57	66	74	82	90	99
31	27	36	44	53	62	71	80	89	98	106
32	28	37	46	55	64	74	83	92	101	110
33	29	39	49	59	69	78	88	98	108	118
34	30	40	50	60	70	80	90	100	110	120
35	33	44	55	66	77	88	98	109	120	131
36	35	46	58	69	81	92	104	115	127	138
37	39	51	64	77	90	103	116	129	142	154
38	40	54	67	80	93	107	120	133	147	160
39	42	56	70	84	98	112	126	140	154	168
40	45	60	75	90	105	120	135	150	166	181

[1] When smooth values for 16-foot logs are needed, use should be made of the formula $V = 0.79D^2 - (2D+4)$, in which D is top diameter inside bark in inches.

Table 46.--Scribner scale of 16-foot logs computed from formula $V = 0.79D^2-(2D+4)$ and read to nearest board foot

Top diameter of log inside bark (full inches)	Volume of log by additional fraction of inch of top diameter inside bark									
	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.
6	12	13	14	15	16	16	17	18	19	20
7	21	22	23	23	24	25	26	27	28	30
8	31	32	33	34	35	36	37	38	40	41
9	42	43	44	46	47	48	50	51	52	54
10	55	56	58	59	61	62	64	65	67	68
11	70	71	73	74	76	77	79	81	82	84
12	86	87	89	91	93	94	96	98	100	102
13	104	105	107	109	111	113	115	117	119	121
14	123	125	127	129	131	133	135	137	139	142
15	144	146	148	150	153	155	157	159	162	164
16	166	169	171	173	176	178	180	183	185	188
17	190	193	195	198	200	203	206	208	211	213
18	216	219	221	224	227	229	232	235	238	240
19	243	246	249	252	255	257	260	263	266	269
20	272	275	278	281	284	287	290	293	296	299
21	302	306	309	312	315	318	321	325	328	331
22	334	338	341	344	348	351	354	358	361	364
23	368	371	375	378	382	385	389	392	396	399
24	403	407	410	414	418	421	425	429	432	436
25	440	444	447	451	455	459	463	466	470	474
26	478	482	486	490	494	498	502	506	510	514
27	518	522	526	530	534	538	543	547	551	555
28	559	564	568	572	576	581	585	589	594	598
29	602	607	611	616	620	624	629	633	638	642
30	647	652	656	661	665	670	675	679	684	688
31	693	698	703	707	712	717	722	726	731	736
32	741	746	751	756	761	765	770	775	780	785
33	790	795	800	805	810	816	821	826	831	836
34	841	846	852	857	862	867	873	878	883	888
35	894	899	904	910	915	921	926	931	937	942
36	948	953	959	964	970	975	981	987	992	998
37	1,004	1,009	1,015	1,021	1,026	1,032	1,038	1,043	1,049	1,055
38	1,061	1,067	1,072	1,078	1,084	1,090	1,096	1,102	1,108	1,114
39	1,120	1,126	1,132	1,138	1,144	1,150	1,156	1,162	1,168	1,174
40	1,180	1,186	1,192	1,198	1,205	1,211	1,217	1,223	1,229	1,236
41	1,242	1,248	1,255	1,261	1,267	1,274	1,280	1,286	1,293	1,299
42	1,306	1,312	1,318	1,325	1,331	1,338	1,344	1,351	1,358	1,364

Table 47.--Doyle log rule

Top diameter of log inside bark (inches)	Volume of log by length						
	8 feet	10 feet	12 feet	14 feet	16 feet	18 feet	20 feet
	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.
8	8	10	12	14	16	18	20
9	13	16	19	22	25	28	31
10	18	23	27	32	36	41	45
11	25	31	37	43	49	55	61
12	32	40	48	56	64	72	80
13	41	51	61	71	81	91	101
14	50	63	75	88	100	113	125
15	61	76	91	106	121	136	151
16	72	90	108	126	144	162	180
17	85	106	127	148	169	190	211
18	98	123	147	172	196	221	245
19	113	141	169	197	225	253	281
20	128	160	192	224	256	288	320
21	145	181	217	253	289	325	361
22	162	203	243	284	324	365	405
23	181	226	271	316	361	406	451
24	200	250	300	350	400	450	500
25	221	276	331	386	441	496	551
26	242	303	363	424	484	545	605
27	265	331	397	463	529	595	661
28	288	360	432	504	576	648	720
29	313	391	469	547	625	703	781
30	338	423	507	592	676	761	845
31	365	456	547	638	729	820	911
32	392	490	588	686	784	882	980
33	421	526	631	736	841	946	1,051
34	450	563	675	788	900	1,013	1,125
35	481	601	721	841	961	1,081	1,201
36	512	640	768	896	1,024	1,152	1,280
37	545	681	817	953	1,089	1,225	1,361
38	578	723	867	1,012	1,156	1,301	1,445
39	613	766	919	1,072	1,225	1,378	1,531
40	648	810	972	1,134	1,296	1,458	1,620

Table 48.--Spaulding log rule (Columbia River)

Top diameter of log inside bark (inches)	Volume of log by length							
	12 feet	14 feet	16 feet	18 feet	20 feet	30 feet	40 feet	50 feet
	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.	Bd.ft.
10	38	44	50	57	63	94	126	157
11	47	55	63	70	78	117	156	195
12	58	67	77	87	96	144	192	241
13	71	82	94	106	118	176	236	295
14	86	100	114	129	143	214	286	358
15	103	120	137	154	171	257	342	429
16	121	141	161	181	201	302	402	504
17	141	164	188	211	235	352	470	587
18	162	189	216	243	270	405	540	675
19	184	214	245	276	306	459	612	766
20	207	241	276	310	345	517	690	862
21	231	269	308	346	385	577	770	962
22	256	298	341	384	426	639	852	1,066
23	282	329	376	423	470	705	940	1,175
24	309	360	412	463	515	772	1,030	1,287
25	337	393	449	505	561	842	1,122	1,404
26	366	427	488	549	610	915	1,220	1,525
27	396	462	528	594	660	990	1,320	1,650
28	427	498	569	640	711	1,067	1,422	1,779
29	459	535	612	688	765	1,147	1,530	1,912
30	492	574	656	738	820	1,230	1,640	2,050
31	526	613	701	789	876	1,314	1,752	2,191
32	561	654	748	841	935	1,402	1,870	2,337
33	597	696	796	895	995	1,492	1,990	2,487
34	634	739	845	951	1,056	1,584	2,112	2,641
35	673	785	897	1,009	1,121	1,682	2,242	2,804
36	713	831	950	1,069	1,188	1,781	2,376	2,970
37	755	880	1,006	1,132	1,258	1,886	2,516	3,145
38	798	931	1,064	1,197	1,330	1,995	2,660	3,325
39	843	983	1,124	1,264	1,405	2,107	2,810	3,512
40	889	1,037	1,185	1,333	1,481	2,222	2,962	3,704
45	1,134	1,323	1,512	1,701	1,890	2,835	3,780	4,725
50	1,404	1,638	1,872	2,106	2,340	3,510	4,680	5,850
55	1,700	1,983	2,266	2,550	2,833	4,249	5,666	7,083
60	2,028	2,366	2,704	3,042	3,380	5,070	6,760	8,450
65	2,390	2,789	3,186	3,585	3,983	5,975	7,966	9,959
70	2,789	3,253	3,718	4,183	4,648	6,971	9,296	11,660

Table 49.--International log rule (saw kerf, 1/4 inch)[1]

Top diameter of log inside bark (inches)	Volume of log by length						
	8 feet	10 feet	12 feet	14 feet	16 feet	18 feet	20 feet
	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.	Bd. ft.
4		5	5	5	5	5	10
5	5	5	10	10	10	15	15
6	10	10	15	15	20	25	25
7	10	15	20	25	30	35	40
8	15	20	25	35	40	45	50
9	20	30	35	45	50	60	70
10	30	35	45	55	65	75	85
11	35	45	55	70	80	95	105
12	45	55	70	85	95	110	125
13	55	70	85	100	115	135	150
14	65	80	100	115	135	155	175
15	75	95	115	135	160	180	205
16	85	110	130	155	180	205	235
17	95	125	150	180	205	235	265
18	110	140	170	200	230	265	300
19	125	155	190	225	260	300	335
20	135	175	210	250	290	330	370
21	155	195	235	280	320	365	410
22	170	215	260	305	355	405	455
23	185	235	285	335	390	445	495
24	205	255	310	370	425	485	545
25	220	280	340	400	460	525	590
26	240	305	370	435	500	570	640
27	260	330	400	470	540	615	690
28	280	355	430	510	585	665	745
29	305	385	465	545	630	715	800
30	325	410	495	585	675	765	860
31	350	440	530	625	720	820	915
32	375	470	570	670	770	875	980
33	400	500	605	715	820	930	1,045
34	425	535	645	760	875	990	1,110
35	450	565	685	805	925	1,050	1,175
36	475	600	725	855	980	1,115	1,245
37	505	635	770	905	1,040	1,175	1,315
38	535	670	810	955	1,095	1,245	1,390
39	565	710	855	1,005	1,155	1,310	1,465
40	595	750	900	1.060	1.220	1.380	1.540

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[1] Allowance for shrinkage in thickness, 1/16 inch per inch. Taper allowance, 1/2 inch per 4-foot section. Formula for volume of 4-foot section, $V = (0.22D^2 - 0.71D)\ 0.9048$.

CONVERSION EQUIVALENTS

Length and Distance

1 foot = 12 inches = 0.3333 yard = 0.06061 rod = 0.01515 chain (s) = 0.0001894 mile = 0.3048 meter.

1 inch = 0.08333 foot = 0.02778 yard = 2.540 centimeters.

1 chain (surveyor's) = 66 feet = 4 rods = 100 links = 0.0125 mile = 20.1168 meters.

1 link = 7.92 inches = 0.66 foot.

1 rod = 16.5 feet = 5.5 yards = 25 links = 0.25 chain (s) = 0.003125 mile.

1 yard = 3 feet = 36 inches = 0.914402 meter.

1 mile = 63,360 inches = 8,000 links = 5,280 feet = 1,760 yards = 320 rods = 80 chains (s) = 1.60935 kilometers.

Area

1 sq.ft. = 144 sq. in. = 0.1111 sq. yd.. = 0.0929034 sq. meter..

1 sq. mile = 27,878,400 sq. ft. = 3,097,600 sq. yds. = 640 acres = 1 section = 259 hectares = 2.59 sq. kilometers.

Plot Dimensions

1 acre. Side of square = 208.71 feet = 3.162 chains (s) = 12.65 rods.

Radius of circle = 117.75 feet = 1.784 chains (s) = 7.14 rods.

1/2 acre. Side of square = 147.57 feet = 2.236 chains (s) = 8.94 rods.

Radius of circle = 83.26 feet = 1.262 chains (s) = 5.05 rods.

1/4 acre. Side of square = 104.35 feet = 1.581 chains (s) = 6.32 rods.

Radius of circle = 58.88 feet = 0.892 chain (s) = 3.57 rods.

1/5 acre. Side of square = 93.34 feet = 1.414 chains (s) = 5.66 rods.

Radius of circle = 52.66 feet = 0.798 chain (s) = 3.19 rods.

1/10 acre. Side of square = 66 feet = 1 chain (s) = 4 rods. Radius of circle = 37.24 feet = 0.564 chain (s) = 2.26 rods.

1/40 acre. Side of square = 1/2 chain (s) = 33 feet. Radius of circle = 18.62 feet = 0.282 chain (s) = 1.13 rods.

1/160 acre. Side of square = 1/4 chain (s) = 16-1/2 feet. Radius of circle = 9.31 feet = 0.141 chain (s) = 0.564 rod.

Surveyor's Square Measure

1 acre = 43,560 square feet = 4,840 square yards = 160 square rods = 10 square chains (s) = 4,046.87 square meters = 0.404687 hectare.

1 section = 1 square mile = 640 acres = 16 forties = 102,400 square rods = 3,097,600 square yards = 259 hectares.

1 township = 36 sections = 23,040 acres.

Volume

1 cubic foot = 1,728 cubic inches = 0.028317 cubic meter.

1 cubic yard = 46,656 cubic inches = 27 cubic feet = 0.76456 cubic meter.

1 cubic meter = 35.3145 cubic feet = 61,023.5 cubic inches = 1.30794 cubic yards.

1 cubic foot per acre = 0.06997 cubic meter per hectare.

1 cubic meter per hectare = 14.2913 cubic feet per acre.